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Mechanized annual cropping on low fertility acid soils in the humid tropics

A case study of the Zanderij soils in Suriname

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Contents

Preface

This report is based on research carried out jointly by the Faculty of Natural Resources of the University of Suriname and Wageningen Agricultural University, the Netherlands. The project, entitled 'The permanent cultivation of rainfed annual crops on the loamy soils of the Zanderij formation', was formulated within the context of a formal agreement for research cooperation between the two universities. Its justification was found in the interest the Suriname government had in the future agricultural developments of these low fertility acid soils.

The project was financed by the two universities. During the first few years a substantial contribution to the project funds was received from the Directorate General for Development Cooperation of the Dutch Ministry of Foreign Affairs.

Although the project officially started in 1977, the research was a continuation of investigations initiated five years earlier by the Centre for Agricultural Research (CELOS) and the Agricultural Experiment Station. The project was discontinued at the end of 1983 when circumstances beyond the partners' control prevented the agreement from being renewed.

CELOS served as the project headquarters and supplied laboratory, technical and administrative facilities, and personnel. Its director was the official project administrator.

The field work was carried out partly on the project's own experimental farm at Kabo, and partly on the Coebiti farm of the Experimental Farms Foundation (STIPRIS). STIPRIS provided support for this work at Coebiti by making personnel, land and equipment available.

The research was monitored by the 'Begeleidings Commissie Suriname projecten' (Technical Steering Committee) consisting of members representing both universities and the Suriname Ministry of Agriculture. General matters regarding the cooperation between the two institutes were the responsibility of the bipartite 'Samenwerkings Overeenkomst Commissie' (Cooperation Agreement Committee).

The publication in its present form is the edited version of an interim report prepared in 1982 by the project staff under the supervision of the teamleader Dr. J.F. Wienk. Dr. B.H. Janssen of the Department of Soil Science and Plant Nutrition of Wageningen Agricultural University, who was involved in the supervision of part of the research, rewrote some chapters and edited the final report. In the last stages of this work he was assisted by Dr. J.F. Wienk.

The study shows that mechanized annual cropping in this ecologically problematic part of the tropics presents a number of problems which so far had not come to light and therefore had not been taken into account. The results provide a useful contribution to the existing information on the management of low fertility acid soils when used for annual cropping.

Wageningen, January 1990 Samenwerkings Overeenkomst Commissie

1 Scope of the research

Until recently, low fertility acid soils in the humid tropics of South America and Africa were used for the cultivation of annual crops within the shifting cultivation system only. The obvious reason for this was their low productivity. In shifting cultivation crops make use of the nutrients set free by burning part of the forest vegetation and by the mineralization of easily decomposable organic matter. These supplies being exhausted after two to five crops, farmers have to abandon the land, and forest takes over again.

In many countries population growth is forcing scientists to find a way of using poor soils. Various institutes, such as the Centro Internacional de Agricultura Tropical (CIAT, Colombia), the Centro de Pesquisa Agropecuaria do Cerrado (CPAC, Brazil), the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA, Brazil), the International Institute for Tropical Agriculture (IITA, Nigeria), the Instituto Nacional de Investigación y Promoción Agraria (INIPA, Peru) and the North Carolina State University (NCSU, USA), have devised intensive research programmes on this topic, alone or in joint projects.

Where increased population pressure is the main driving force behind such studies, the research is, as a matter of course, aimed at solving the problems encountered in smallholder farming systems with a low degree of mechanization.

In Suriname, however, the situation is different in two important respects:

1 there is no pressing necessity to use the low fertility acid soils for agriculture;
2 because labour is scarce and expensive a high degree of mechanization is required once it is decided to farm on these soils.

This report presents the main results of a project entitled: 'Permanent Cultivation of Rainfed Annual Crops on the Loamy Soils of the Zanderij Formation' which was one of the projects in a joint research programme of Wageningen Agricultural University, the Netherlands, and the University of Suriname. Another, closely related project is 'Human Interference in the Tropical Rainforest Ecosystem'. Both projects studied possible uses of the rainforest area in Suriname.

The objectives of the annual crops project were

1 to analyse the chemical, physical and biological changes taking place in and above the soil when rainforest is replaced by annual crops;
2 to identify the factors limiting the production of annual crops and to design methods to alleviate these constraints;
3 to indicate which crops are most promising and how they should be cultivated;
4 to find out what machinery would be most appropriate under the prevailing conditions;
5 to develop annual cropping systems within the framework of mechanized farming.

These objectives required the continuous participation of specialists in crop husbandry, soil science and fertilizer use, tillage, agricultural engineering and crop protection. Special studies of shorter duration were made on weeds and on soil fauna.

The introductory sections (2 and 3) of this report give a general picture of Suriname and of the Zanderij Formation. They are followed by a section describing the original conditions, i.e. under forest, on the experimental sites. Sections 5 to 9 deal with the five objectives mentioned above. The main conclusions and recommendations are summarized in Section 10.

2 Suriname

2.1 Geography

Suriname, situated on the northeastern coast of South America, has an area of just over 163 000 km². It lies between latitudes 2° and 6° north and between longitudes 54° and 58° west, and is bordered by the Atlantic Ocean to the north, Guyana to the west, French Guiana to the east and Brazil to the south.

Suriname is divided into three major physiographic regions: the coastal plain, the Zanderij belt and the interior uplands (Fig. 1).

The coastal plain, covering 20 000 km² and comprising an old (Pleistocene) and a young (Holocene) coastal plain, is about 40 km wide in the east and 120 km in the west. This nearly flat region mainly comprises heavy marine clay deposits; the highest point is about 10 m above sea level. In the central and eastern parts of the young coastal plain sand ridges that sometimes form extensive complexes occur. The sand may contain variable amounts of shells.

The Zanderij belt is a narrow, more or less continuous strip of predominantly

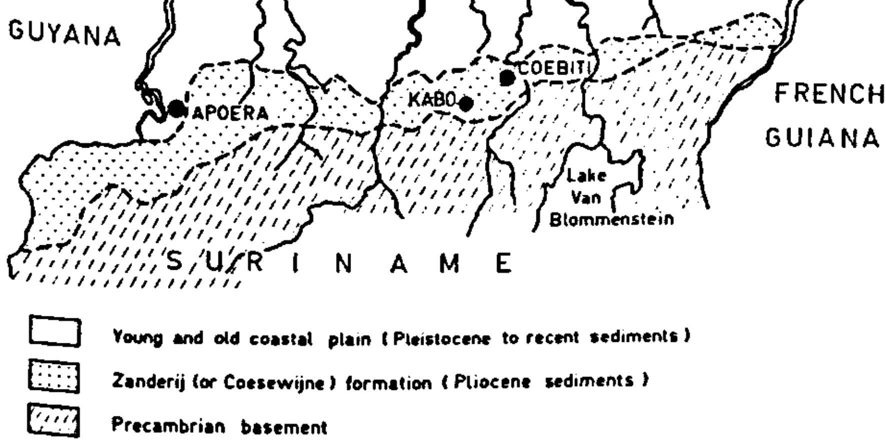

Fig. 1. Northern Suriname with major physiographic regions.

sandy soils running east–west. It is 5-10 km wide in the east and 60-70 km in the west and covers 8750 km^2. Because the vegetation in large parts has a savanna character, the region is often referred to as 'the savanna belt'. Most of the area, however, is covered with tropical rainforest. The area is gently undulating; its maximum elevation in the south is 50 m.

The uplands are part of the Guiana Shield. Their residual soils are derived from igneous and sedimentary Precambrian rocks. This sparsely populated region, comprising more than four-fifths of the country, is mainly gently to moderately rolling with some steep ground in the relatively few mountainous areas. The highest point is 1280 m.

2.2 Agriculture

In 1981 about 88 per cent of the country's 350 000 inhabitants lived in the coastal plain, with the capital, Paramaribo, as the main urban centre where approximately 135 000 people were concentrated. Most of the agricultural activities are restricted to the young coastal plain and to an area of the old coastal plain south of Paramaribo.

Farming the heavy clay soils, which mostly lie below high-tide level, requires extensive drainage in the form of polders. Moreover, cambered beds and extensive open drainage systems are necessary even on most of the ridges. This hinders mechanized farming. Modern agricultural machinery, and even aircraft are used for rice, but for other crops the heavy soils in combination with the humid climate cause problems of workability and trafficability.

The main crops are rice, citrus, sugar cane and bananas, which are grown on a medium to large scale (Table 1). Other food crops and vegetables are grown by small farmers, mainly on the sand ridges.

Table 1. Areas and gross production values of Suriname's agricultural commodities in 1980. From Anon. (1981).

Crop	Area ha	Value SRG[a]) × 1000	Crop	Area ha	Value SRG × 1000
rice	64 956	63 634	vegetables	719	6 546
oil palm	2 557	4 091	cocoa	250	169
sugar cane	2 392	4 085	groundnut	208	687
citrus	1 933	5 316	pulses	189	271
banana and plantain	1 909	12 509	maize	183	261
			coffee	152	486
coconut	1 097	822	other crops	1 074	5 925
total	77 619	104 775			
pastures	14 937				

[a]) 1 USD = SRG 1.80.

Apart from the Amerindian and Bush Negro settlements along the rivers, the interior uplands and the Zanderij belt are virtually uninhabited. The main agricultural activity in these regions is subsistence shifting cultivation. A recent development is the introduction of livestock and oil palm; the area of the latter exceeded 4000 ha in 1982.

The Zanderij belt soils are chemically less fertile than the soils of the coastal plain but their physical properties were believed to be better. Their sandy nature, higher permeability and natural drainage do not as a rule require cambered beds, open drains or other techniques to cope with excess water during the rainy season. Therefore there are fewer obstacles to mechanized farming systems than in the coastal plain. This largely explains the government's agricultural interest in this area.

2.3 Agricultural research on Zanderij soils

Access to the Zanderij belt was greatly improved in the 1960s following the construction of a road network to exploit the rainforest for its timber. In 1969 a 73-ha experimental farm, Coebiti, cleared from exploited rainforest, was opened up in the northern part of this region to study the agricultural potential of the Zanderij belt. It was extended to 100 ha in 1975. The soils of Coebiti were considered to be representative of the Zanderij belt.

Initially, the research at Coebiti focused on pastures and perennial crops. Citrus, oil palm, coconut and bananas were monitored. Areas not immediately planted to grass or a particular crop were sown to kudzu. In 1972 annual crops were added to the programme and observation plots of cassava, maize, sorghum, groundnut, soybean, cowpea and mungbean were established. Most of this early, mainly exploratory, research on annual crops was carried out by individual researchers from Wageningen Agricultural University, the Netherlands, operating from the Centre for Agricultural Research (CELOS) near Paramaribo. In 1976 this work was reformulated, resulting in the project whose results are described in this report.

The project started late 1977. To meet its objectives a 25-ha farm, Kabo, located in the southern part of the Zanderij belt (Fig. 1) some 40 km southwest from Coebiti, was cleared from unexploited rainforest. Clearing started in 1978 and was completed early 1979. Since that time both farms have been used for field experiments. To distinguish between the farm areas at Coebiti cleared in 1969 and 1975, the latter will be referred to as Coebiti extension.

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3 Physical environment of the Zanderij belt

3.1 Climate

According to Köppen's classification the major part of Suriname has a Tropical Rainforest (Af) or a Tropical Monsoon Climate (Am). The climate of the Zanderij belt is partly Af and partly Am. At the Kabo and Coebiti Experimental Farms an Af climate prevails; that is, all months have a mean rainfall of more than 60 mm.

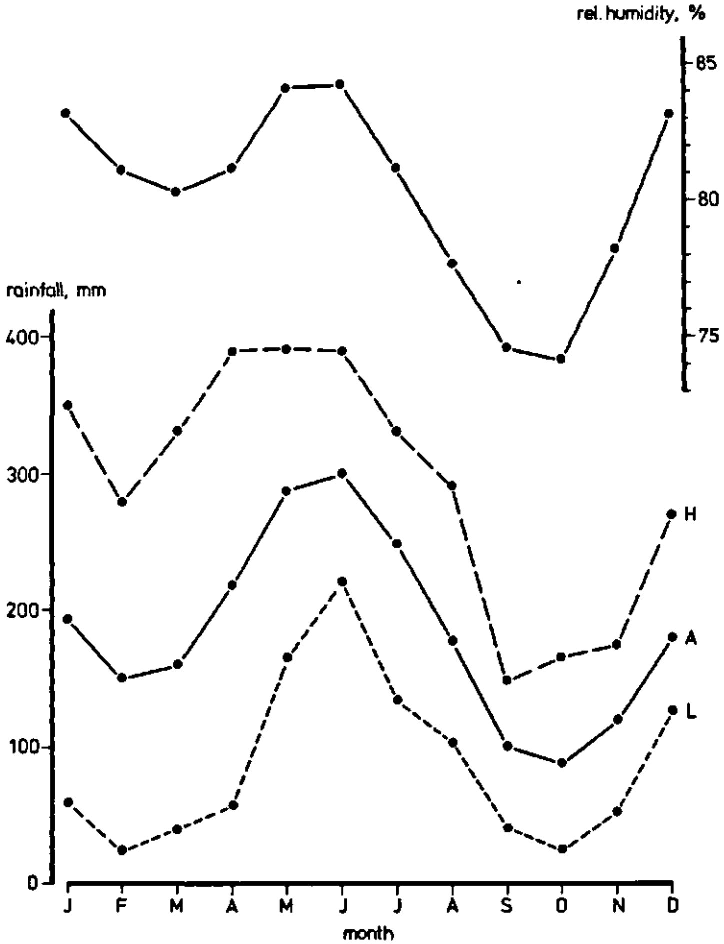


Fig. 2. Average monthly relative air humidity and monthly rainfall at Zanderij Airport (1952-1980). A = average; H, L = high and low 10 per cent limits, respectively.

Meteorological recording at Coebiti and Kabo started in 1971 and 1980, respectively. The nearest station for which long-term meteorological data are available is Zanderij Airport, about 35 km east of Coebiti. Rainfall data from both locations over the period 1971-1980 show close similarity. The data available for Kabo are still too few to draw conclusions as to a possible similarity with Zanderij Airport, but large differences are not expected. Therefore, meteorological data from Zanderij Airport have been used to characterize the climate of the two farms.

The mean annual rainfall for Zanderij Airport is 2221 mm. Distribution is bimodal so that two rainy and two dry seasons are distinguished. According to the Meteorological Service these seasons are as follows:

Short rainy season	21 November - 14 January
Short dry season	15 January - 19 April
Long rainy season	20 April - 14 August
Long dry season	15 August - 20 November

Average monthly rainfall varies from 300 mm (June) to 84 mm (October) (Fig. 2). Most rain falls in the afternoon between 14.00 and 17.00 h, which is when the highest daily intensities are also recorded. The driest period of the day is 09.00 – 10.00 h. Generally, rainfall intensity from January to April is lower than during the rest of the year.

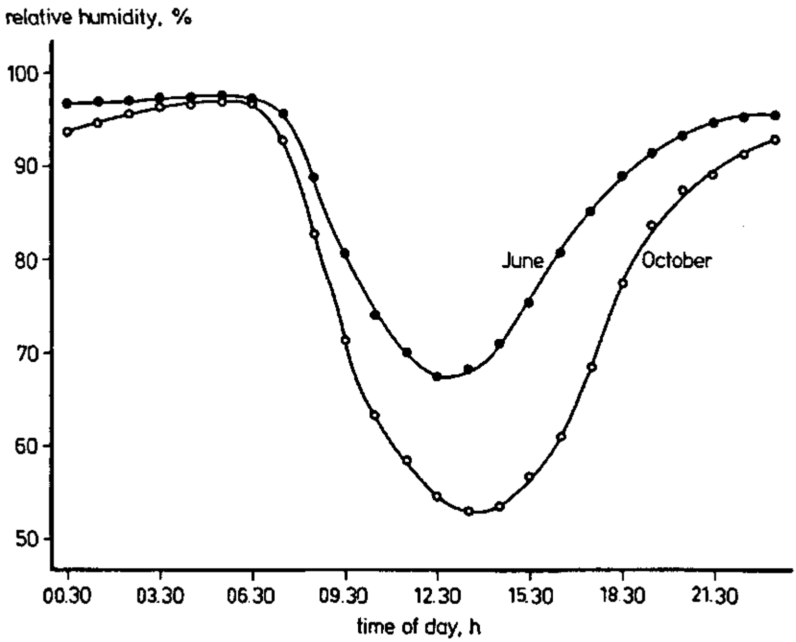


Fig. 3. Average hourly relative air humidity for June and October at Zanderij Airport (1952-1980).

The mean daily relative humidity closely follows the seasons (Fig. 2). During the rainy seasons the average relative humidity is 84 per cent, whereas in the short dry season it is 80 per cent and in the long dry season it is 74 per cent. During the night relative humidity increases to about 96 per cent, dropping on average to 53-68 per cent during the day, depending on the season (Fig. 3).

Mean monthly temperature varies from 25.7°C (February) to 28.0°C (October) (Fig. 4). Daily temperature fluctuations are much larger – on an annual basis the mean daily minimum temperature is 21.9°C and the mean maximum is 31.9°C. The highest mean daily maximum temperature (34°C) is recorded in October and the lowest mean minimum (20.5°C) in January.

Average duration of sunshine does not reflect the bimodal rainfall distribution pattern. September, with a maximum of 7.7 hours of sunshine, is the sunniest month. From December to June sunshine varies little around an average of 4.5 hours. In spite of a high average rainfall of 245 mm, July has much more sunshine than the drier months of February and March (Fig. 4).

Average wind speeds are low (1.7 m s^{-1}). Wind speeds from 8.5 to 10.8 m s^{-1}

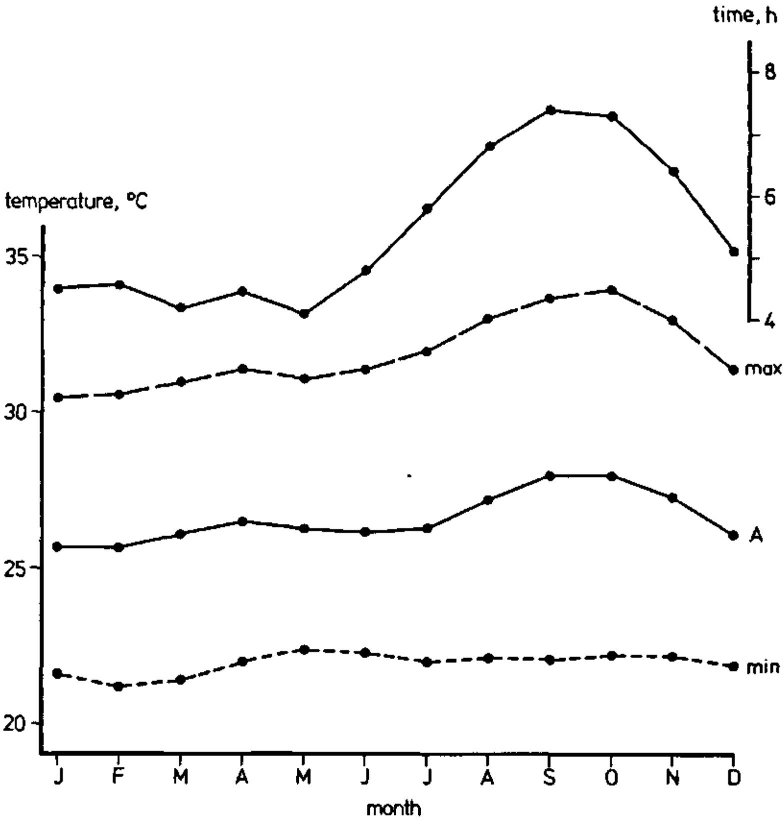


Fig. 4. Average duration (h) of sunshine (07.00-17.00 h) and average maximum, mean and minimum monthly temperatures at Zanderij Airport (1952-1980).

have been recorded in only 0.28 per cent of the cases. Speeds of 20-30 m s^{-1} have been recorded occasionally during thunder storms, but only for very short periods. Suriname is not affected by tropical cyclones.

Data on Class-A pan evaporation are available for Zanderij Airport for the period 1973-1980. Evaporation ranges from 117 mm in December to 171 mm in September and October.

Temperature distribution allows year-round crop growth, but rainfall, especially its distribution and reliability, is a limiting factor for the production of annual crops. Climate-related constraints will be discussed in Sections 6 to 9.

3.2 Soils

The Zanderij Formation consists of sediments up to several metres thick, with textures of sand to sandy clay, overlying the crystalline basement rock of the Guiana Shield. They are assumed to have been deposited by a system of braiding rivers during the Pliocene (Van der Eijk, 1957; Krook & Mulders, 1971). The area generally slopes northwards, with elevations of 30 to 50 m above sea level in the south, decreasing to about 10 m in the north. Despite incision by creeks, the area has a flat to undulating topography, with some steeper slopes along drainage lines.

The original material was intensively weathered before transportation and sedimentation and therefore the sediments were already poor in nutrients when soil-forming processes started.

According to Bennema (1982) most loamy Zanderij soils belong to the Yellow Kaolinitic Oxisols intergrading towards Ultisols. The Yellow Kaolinitic Oxisols are extensive on sediments of Tertiary origin in South America, especially in Brazil. They have a low iron content and a low stability. Their subsoils have a bright brown to yellowish brown colour. Clay content generally increases with depth. In Suriname these soils are described as brown sands and brown loams (Table 2).

During the rainy season water might be stagnant at centres of nearly level plateaus and on footslopes, especially where a porous soil overlies a less permeable substrate. This periodic waterlogging causes mobilization of iron, destruction and removal of clay, and the dispersion of organic matter and its accumulation at great depth. Soil colour gradually becomes duller. Eventually a bleached eluvial A2 horizon of white sand is formed, slowly increasing in thickness. The export of soil material lowers the soil surface, resulting in more waterlogging and thus intensifying the process. Areas of bleached white sand have been and are still being formed in this way (Lucas et al., 1982).

The sand fraction predominantly consists of medium-sized (250-500 μm) quartz and the clay fraction of kaolinite. Organic matter contributes more to CEC than clay. Soil pH(H_2O) ranges from 4.6 to 5.2 and the sum of ionic equivalents of exchangeable bases ranges from 1 to 10 mmol kg^{-1}.

The brown loams have the higher values of these ranges but are still chemically

Table 2. General characteristics of the Zanderij soils in Suriname.

	Bleached	Non-Bleached	
Natural vegetation	savanna and savanna forest	mixed upland forest	
	White sands	Brown sands	Brown loams
Texture, topsoil	sand	sand	loamy sand
subsoil	sand	sand to sandy loam	sandy clay-loam
Approximate area			
proportion[a])	0.4	0.3	0.3
km^2	3 500	2 625	2 625

[a]) Proportion of Zanderij area.

poor. The white sands are so poor that they were ignored in this study. Approximately 40 per cent of the brown loams are unsuitable for arable farming because of swampy creek beds, outcrops of residual stony material, and steep slopes. A large part of the remaining 1575 km^2 is distributed over small patches, bordered by white and brown sands, creeks and steep slopes, which limit their agricultural use.

4 Original conditions on the experimental sites

4.1 Natural vegetation

The Coebiti Experimental Farm was established in an area of exploited forest and savanna, and the Kabo farm in an area of unexploited forest where balata bleeding had been the only recent human activity.

The virgin forest mainly consisted of a mixed mesophytic dryland forest with hydrophytic swamp forest characterized by pina palms (*Euterpe oleracea*) along the creeks.

At Kabo a survey was made of the dryland forest on the 25-ha site chosen for the farm. In the lower strata bugrumaka palm (*Astrocaryum sciophylum*) prevailed. Only a a few herbaceous plants were found. Table 3 presents the numbers of the dominant tree species with a minimum diameter of 40 cm at breast height. In all, 95 species were found. The dominant tree was *Dicorynia guianensis*. All *Manilkara bidentata* trees showed markings of gum collecting. The presence of fairly large numbers of *Goupia glabra*, indicative of old secondary vegetation, suggests that at some time in the past the Kabo forest has been disturbed. 'Terra preta' and some pot fragments found after clearing on the

Table 3. Dominant tree species with a minimum dbh of 40 cm at Kabo site before clearing.

Scientific name	Local name	Number[a])	
		A	B
Dicorynia guianensis (Papilionaceae)	Basralokus	363	256
Manilkara bidentata (Sapotaceae)	Boletri	119	84
Goupia glabra (Celastraceae)	Kopi	88	62
Qualea spp. (Vochysiaceae)	Gronfoeloe	86	61
Sclerolobium melinonii (Papilionaceae)	Djadidja	69	49
Ocotea rubra (Lauraceae)	Wana	66	46
Micropholis guianensis (Sapotaceae)	Zwart Riemhout	51	36
others (less than 50 per species)		577	406
	Total	1419	1000
Leguminosae			
Papilionaceae		494	348
Mimosaceae		72	51
Total		566	399

[a]) A: numbers per 25 ha.
B: numbers per 1000 trees.

highest sandy parts, point at Amerindian occupation long ago.

Cleared areas left under fallow developed a secondary vegetation characterized by *Cecropia sciadophylla*, *C. obtusa* (Moraceae) and *Palicourea guianensis* (Rubiaceae).

The forest at Coebiti was, in principle, similar to the Kabo forest. The vegetation of the savannas in the area is characterized by short grasses and scattered shrub and bushes, with galleries of *Mauritia flexuosa* (Palmae) along drainage lines where the soil is moist.

4.2 Soils

4.2.1 Soil description and classification

Both experimental farms, Coebiti and Kabo, are situated on soils developed in Zanderij sediments. Coebiti farm was initially intended for the study of pasture and perennials, and therefore the soils had to be representative of the Zanderij region. They cover the whole range from the white sands to brown loams mentioned in Table 2. At Coebiti the trials with annual crops showed that only the brown loams might be considered for this type of land use, and therefore for the Kabo farm a site with predominantly sandy-loam and sandy-clay-loam soils was selected.

Coebiti generally has a level topography with slopes from 0 to 2 per cent. At Kabo, plateaus (0-2 per cent), slopes (2-5 per cent) and footslopes (0-2 per cent) are distinguished (Fig. 5).

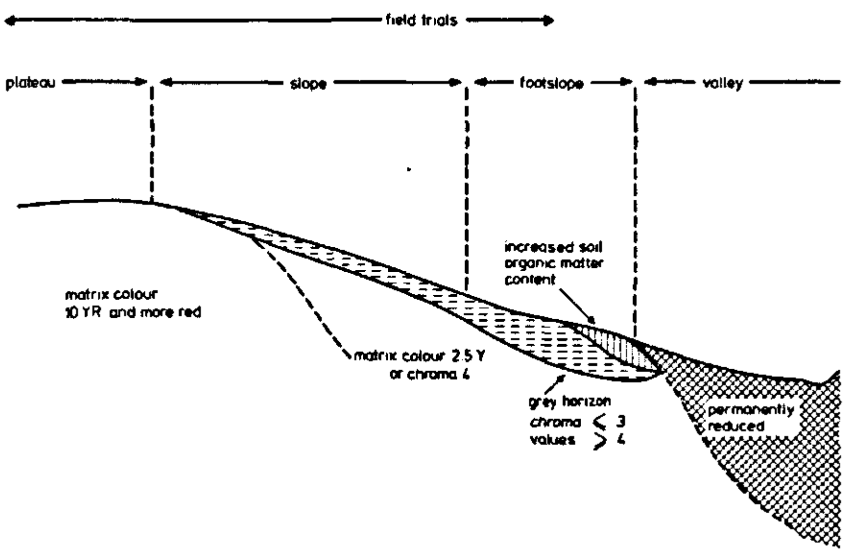


Fig. 5. Schematic toposequence of Kabo soils. From Bruin & Tjoe Awie (1980).

The Coebiti soils were mapped (1:6000) by Van Amson et al. (1974). They distinguished nine soil units, one belonging to the white sands, two to the brown sands, four to the brown loams, and two intermediate between the brown sands and loams. Following the USDA soil classification system (Soil Survey Staff, 1975), the white sands, brown sands, and brown loams can be classified as respectively Typic Quartzipsamment, Orthoxic Quartzipsamment, and Ultic Haplortox. The last group is of most interest for the present report. It can briefly be described as comprising very deep, moderately well to well-drained soils with a brown loamy-sand topsoil and a dull brown to brownish-yellow or orange sandy-clay-loam subsoil. Appendix 1 gives a full description of a representative profile (described when already under cultivation).

In 1977-78 the Soil Survey Service of the Suriname Ministry of Natural Resources made a semi-detailed (1:40 000) survey in the surroundings of the Kabo creek (Taus, 1979). Based on this survey and other data, sites were selected for both projects mentioned in Section 1. Next, in 1979, an area of 96 ha, including 25 ha of the Kabo Experimental Farm that been cleared meanwhile, was surveyed in detail (1:5000). Bruin & Tjoe Awie (1980) distinguished two mapping units on the plateaus and three on the slopes. Furthermore, one valley bottom soil and one soil developed on the Precambrian Basement Complex were mapped, but they did not occur in the experimental area proper.

The major unit of the plateau soils consists of well-drained profiles with a brown loamy-sand or sandy-loam topsoil and a yellowish brown sandy-clay-loam subsoil. Appendix 2 gives an example; this profile was described before clearing the forest. The minor plateau unit is more sandy and is well to excessively drained.

The slope soils often have a grey, generally more sandy layer immediately below a thin dark brown A1 horizon (Fig. 5). Towards the bottom of the slope the grey layer increases in thickness, reaching a maximum of 40 cm. It is hypothesized that this layer is the result of loss of iron and clay, caused by lateral water flow. At the bottom of the slopes the soils have a thick (up to 60 cm) dark topsoil, due to organic matter accumulation.

More than 80 per cent of the Kabo soils belong to the brown loams and can be classified as Haplortox, usually Ultic Haplortox. The remaining, more sandy profiles belong to the brown sands and can be classified as Orthoxic Quartzipsamment.

4.2.2 *Physical soil characteristics*

4.2.2.1 *Soil texture*

Textural compositions of the soil at 0-10, 50-60 and 100-110 cm depths are shown in Fig.6. Because all samples contained more than 55 per cent sand, it was sufficient to draw only the left quarters of the standard texture triangle. Samples were from three brown loams and one brown sand/brown loam at Coebiti and from three brown loams and two brown sands at Kabo, representing the soils used in this research project.

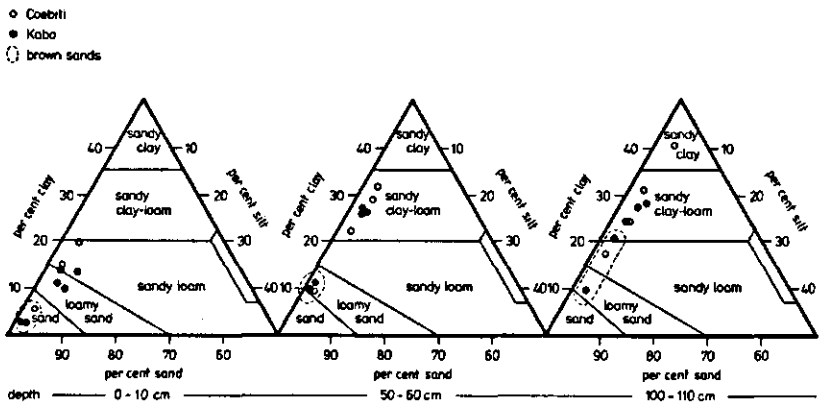


Fig. 6. Textural composition of four Coebiti and five Kabo soils sampled at 0-10, 40-50 and 100-110 cm. Only soils used in the field trials are included.

There were no systematic differences between Coebiti and Kabo. The textures of brown sands at 0-10, 50-60 and 100-110 cm were respectively sand, loamy sand, and sandy loam to sandy clay-loam. The textures of the brown loams at 0-10, 50-60 and 100-110 cm were loamy sand to sandy loam, sandy clay-loam, and sandy clay-loam to sandy clay. These data are in close agreement with those reported by Van Amson et al. (1974) and Bruin & Tjoe Awie (1980). The main sand fraction was medium sand (Fig. 7). The brown sands of Kabo contained somewhat more coarse and very coarse sand and somewhat less very fine sand than the brown loams of Kabo and than the Coebiti soils. At Kabo, topsoil sand was a little coarser than subsoil sand but at Coebiti a similar size distribution was found at all depths.

4.2.2.2 Soil porosity

Data on porosity of Coebiti forest soils were given by Van der Weert (1974), Van der Weert & Lenselink (1972), Van der Weert & Mahesh (1972a). They proposed a practical subdivision of pore volume into three pore-size classes (Table 4). Macropore volume was assumed to be an index of root permeability in soils with a rigid pore structure (sandy soils, generally). The volume of meso- plus macropores, being equal to the volume of air-filled pores at pF 2.0, was used as an index of aeration.

Fig. 8 shows pore-size distributions to 100 cm depth of a Coebiti profile under exploited forest and a Kabo profile under virgin forest. Compared with Kabo, the total pore volume at Coebiti was larger at 0-20 cm and smaller at 20-100 cm, but these differences were probably not significant. There was a more consistent difference between the two profiles in pore-size distribution, Coebiti having relatively more micropores and fewer mesopores and below 20 cm also fewer macropores. Forest exploitation at Coebiti might have caused some soil compac-

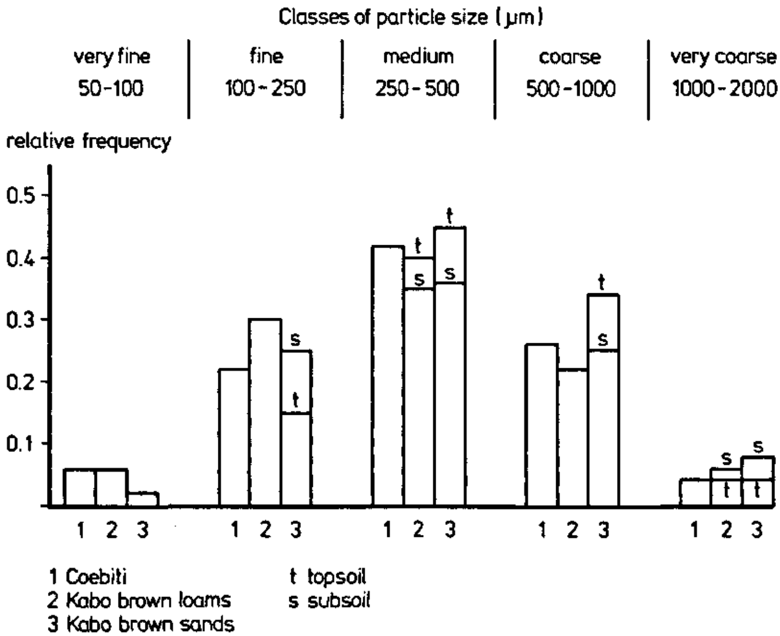


Fig. 7. Particle-size distribution of the sand fraction of Coebiti and Kabo soils. Only soils used in the field trials are included.

Table 4. Subdivision of soil pores, according to Van der Weert (1974).

Pore-size class	Method of determination	Equivalent pore diameter (µ m)
micropores	moisture volume, pF 2.0	< 30
mesopores	air volume, pF 2.0–pF 1.2	30–180
macropores	air volume, pF 1.2	> 180

tion. Macropores suffer most from compaction (Van der Weert & Lenselink, 1972). Nevertheless, as the volume fractions of macropores were more than 0.1 throughout the profile, it is unlikely that mechanical impedance or aeration were limiting root growth.

4.2.2.3 Soil moisture characteristics

There were no substantial differences in the shape of pF curves between Coebiti and Kabo (Fig. 9). The curves for topsoils showed the bend between pF 2.7 and pF 2.0 that is characteristic for sandy soils, whereas the curves of the more clayey subsoils had a more smooth course.

Van der Weert et al. (1973) found that in Coebiti soils field capacity corres-

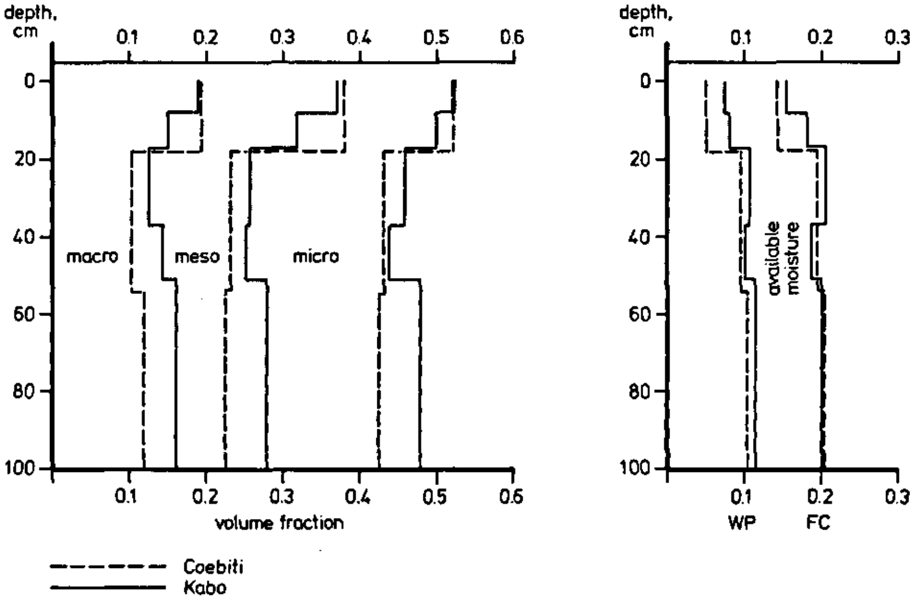


Fig. 8. Pore-size distribution (left) and moisture volume fraction at wilting point (WP) and field capacity (FC) (right) for a Coebiti and a Kabo brown loam under forest. Kabo data from the profile described in Appendix 2.

ponded with soil moisture content at pF 2.0 rather than pF 2.5. Therefore the difference in soil moisture content between pF 2.0 and pF 4.2 was considered as available moisture. Volume fractions of available moisture varied from 0.09 to 0.11 for Coebiti and from 0.08 to 0.10 for Kabo (Fig. 8).

Attempts were made to relate soil moisture contents at pF 2.0 and pF 4.2 to other soil properties. The best relationship was between soil moisture at pF 4.2 and clay content; for Coebiti (Van der Weert et al., 1973) and Kabo forest soil, respectively:

$$MC = 0.28\,(\text{clay}) + 10 \qquad n = 34,\ r^2 = 0.95$$
$$MC = 0.28\,(\text{clay}) + 20 \qquad n = 61,\ r^2 = 0.86,$$

where MC = moisture content ($g\,kg^{-1}$) at pF 4.2,
clay = clay content in $g\,kg^{-1}$, and
n = number of samples.

The correlation coefficients hardly improved when contents of silt and organic C were included in the equations.

Soil moisture content at pF 2.0 proved to be affected primarily by organic matter and silt, but the relationships were not very strong.

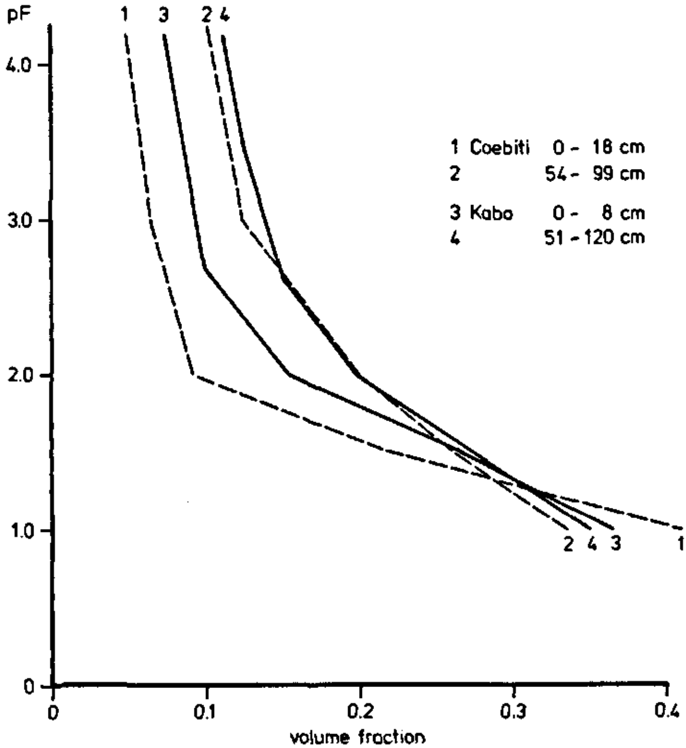


Fig. 9. pF curves for a Coebiti and a Kabo brown loam under forest. Kabo data from the profile described in Appendix 2.

4.2.3 Chemical soil characteristics

Since no data are available on chemical properties of Coebiti soils under forest, the following refers to the Kabo site only, unless stated otherwise.

4.2.3.1 Natural soil fertility

The data presented in Table 5 show that the Kabo forest soils were acid, had a high Al content and a very low base saturation, contained little organic matter and had a low CEC. In topsoils the effective CEC (ECEC) was only one-third of the CEC measured at pH 7. A comparison with data from other loams and brown sands of the Zanderij Formation (Schroo, 1976) shows that Kabo is not an exception.

The Kabo topsoils were a little lower in exchangeable Ca, Mg, K and Al, and consequently in ECEC, than the soils of Yurimaguas in Peru (Bandy & Sanchez, 1982) and of Carimagua in Colombia (Spain, 1982). As their Al saturation relative to ECEC was a little lower (78 vs 86), the Kabo soils were a little

Table 5. Average values of some chemical and physical properties of a cross section of Zanderij and Kabo soils (brown loams and brown sands) before clearing.

	Zanderij[b])	Kabo				
Sample depth, cm	0-30	0-20	20-40	40-60	60-90	90-120
Number of samples	12	118	118	28	28	28
Org C, g kg^{-1}	9.3	12.1	7.6	4.2	2.8	1.7
Org N, g kg^{-1}	0.6	0.87	0.54	0.32	0.25	0.20
C/N, g g^{-1}	16	13.9	14.1	13.1	11.1	8.4
pH(KCl)	4.1	3.7	3.9	4.1	4.1	4.1
pH(H_2O)	5.0	4.2	4.5	4.7	4.7	4.8
Exch. ionic equivalents, mmol kg^{-1}						
Ca	0.7	1.5	0.5	0.3	0.3	0.3
Mg	0.6	0.9	0.3	0.3	0.3	0.3
K	0.3	0.4	0.3	0.1	0.1	0.1
Al	7.3	10.2	9.9	7.3	6.0	4.8
ECEC[a])	9.0	13.1	11.1	8.1	6.8	5.6
Ratio Al/ECEC[a])	0.81	0.78	0.89	0.90	0.88	0.86
CEC, pH7.0	29	33.6	24.3	17.6	14.2	12.6
Ratio ECEC/CEC, pH7.0	0.31	0.39	0.46	0.46	0.48	0.44
P-Bray-I, mg kg^{-1}	2[c])	2.3	1.4	0.9	0.6	0.3
Total P, mg kg^{-1}	n.d[d])	73	70	62	73	n.d.
Total K, mmol kg^{-1}	n.d.	3.2	2.9	2.8	3.8	n.d.
Clay, g kg^{-1}	n.d.	130	220	240	270	n.d.
Bulk density, Mg m^{-3}	n.d.	1.28	1.39	1.37	1.35	n.d.
Available moisture, volume fraction	n.d.	0.14	0.12	0.10	0.10	n.d.

[a]) Calculated from the average values.
ECEC = effective CEC = exchangeable (Ca + Mg + K + Na + Al); exchangeable Na was set at 0.1 mmol kg^{-1} throughout the profile.
[b]) Data from Melitz & Stencker over the full east-west length of the Zanderij Formation, cited by Schroo (1976).
[c]) Truog method.
[d]) n.d. = no data available.

less acid than those in Peru and Colombia. Nevertheless, Kabo soils can be considered as real low fertility acid soils. The subsoils were even poorer than the topsoils, which had accumulated nutrients from organic matter, but the subsoils were less acid.

There was considerable variation among soil samples (Fig. 10). Frequency distribution was more or less normal for organic C, CEC, pH, exchangeable K and Al, but oblique for P-Bray-I and exchangeable Ca and Mg, which were overrepresented in the classes adjacent to zero. The variation among samples taken at short distances proved hardly smaller than that among samples taken far apart. This strong heterogeneity in fertility of forest soils must be the result of very local effects, for instance of fallen leaves, branches and trees, and the

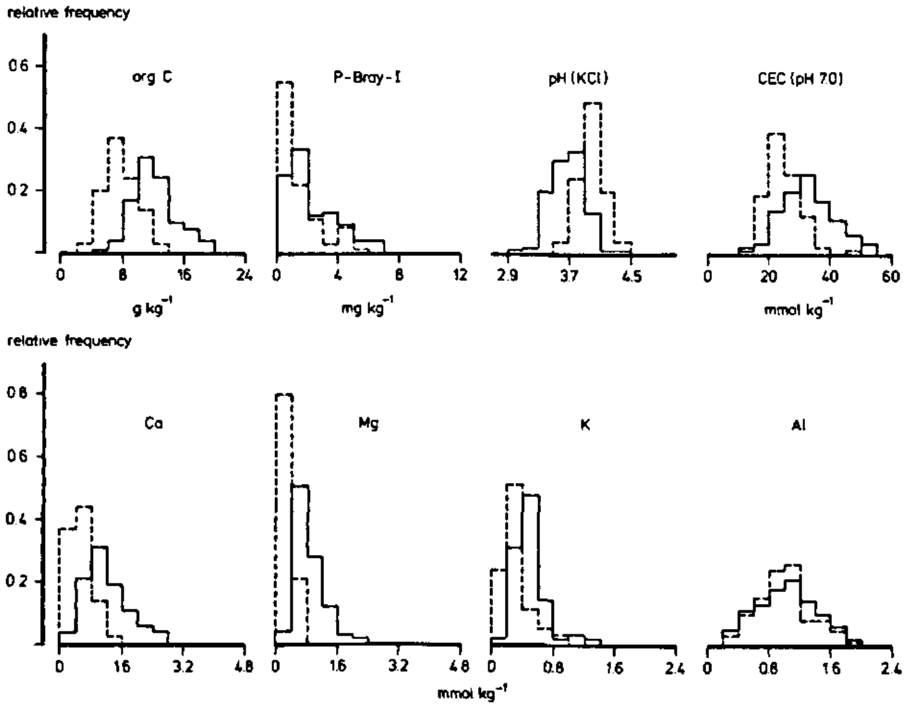


Fig. 10. Relative frequency distribution of organic C, P-Bray-I, pH(KCl), CEC (pH 7.0) and ionic equivalents of exchangeable cations. Samples from 0-20 (———) and 20-40 (--------) cm of Kabo soils under forest; 118 samples from each depth.

activity of leaf-cutting ants (*Atta* spp.).

CEC (pH 7.0) values per g organic C and per g clay estimated with multiple regression analysis varied from 1.9 to 2.5 and 0.03 to 0.09 mmol g^{-1}, respectively. Because organic C made the largest contribution, a small difference in the estimate of its CEC caused a much stronger variation in the estimate of clay-CEC. The estimates of CEC pointed to a poor quality of soil organic matter and to a low activity of kaolinite. The rather high C-N ratio also indicated that the organic matter was of a poor quality.

4.2.3.2 Nutrients in standing forest

The project 'Human Interference in the Tropical Rainforest Ecosystem', mentioned in Section 1, studied how many nutrients were stored in the living phytomass, litter and soil (Table 6). The amounts of 'available' nutrients were much smaller, but the total amounts of N and P in the soil were much larger than those in the living phytomass. Total P proved about 50 times as much as P-Bray-I, but this estimate is based on only a few analyses of total P.

Table 6. Amounts of dry matter (t ha^{-1}) and nutrients (kg ha^{-1}) in living forest phytomass, litter and soil. Kabo (after Ohler, 1980).

	Dry matter	Nutrients					
		N	P	P[d])	K	Ca	Mg
Living phytomass[a])	415	1478	102		1270	2650	241
Litter[b])	35	231	10		43	211	29
Total above soil	450	1709	112		1313	2861	270
Soil, 0-50 cm[c])	80	3861	13	273	66	126	40
50-170 cm	50	4008	7	804	47	47	43
Total soil	130	7869	20	1077	113	173	83
Roots	65	561	37		246	272	50
Total ecosystem	645	10139		1226			

[a]) Excluding roots.
[b]) Including dead trees.
[c]) Soil data refer to organic N, P-Bray-I, and exchangeable ionic equivalents of K, Ca and Mg.
[d]) Estimates of total P, based on analyses of only a few soil samples.

Compared with rainforest elsewhere (Jaffré, 1985) the volume and the nutrient content of the phytomass do not point to an extremely low nutrient level. For its yearly increment the forest phytomass depends on recycling nutrients rather than on nutrients freshly supplied by the soil. More details are given by Boxman et al. (1985a) and by Poels (1987).

4.2.4 Soil and litter fauna

Soil and litter fauna were studied at Kabo under primary and secondary forest and under field crops, with the aim of obtaining information on changes in faunal composition brought about by clearing. It was expected that this knowledge could be helpful in understanding soil problems encountered in the project.

The studies were carried out between November 1981 and May 1982. This section deals with the results obtained under primary forest; the other results are discussed in Section 5.2.3.

4.2.4.1 Methods

Litter was defined as the dead organic material lying on the soil surface, and not mixed with mineral soil particles. It was sampled at a maximum distance of 3 m from trees of the two most dominant species, viz. *Dicorynia guianensis* and *Manilkara bidentata* (Table 3). Animals were extracted from litter in 50-cm diameter Berlese funnels.

Soil samples were also taken at a maximum distance of 3 m from trees of *Dicorynia guianensis*. The mesofauna (animal length 0.2-2.0 mm) was sampled at depths of 0-2.5, 2.5-5.0, 7.5-10.0, 12.5-15.0 and 17.5-20.0 cm.

The animals were extracted from the soil samples in a modified MacFadyen (1961) high gradient extraction apparatus. The bulk density and soil organic C of these soil samples were also assessed. The samples were sieved (2.0 mm) and pieces of leaves, twigs, etc. (i.e. crude organic materials) were sorted out and weighed.

To extract the macrofauna (longer than 2.0 mm), soil samples measuring 24 x 24 x 15 (depth) cm, were carefully sorted by hand. Separate samples for determination of bulk density and organic C were taken at depths of 2-7 cm and 10-15 cm, using a ring auger.

4.2.4.2 Composition of the fauna

The total numbers of meso- and macrofauna (Table 7) were a little more than the 85 500 m^{-2} found by Van der Drift (1963) under primary forest, but many more mesofauna and far fewer macrofauna were found per m^2 (85 000 vs 31 500 mesofauna animals per m^2 and 4810 vs 54 000 macrofauna animals per m^2). In an Amazon area Beck (1971) extracted about 100 000 animals per m^2 (meso- and macrofauna) from litter and soil up to a depth of 6.5 cm, which is close to the number at Kabo.

Diversity was highest for mesofauna, although more taxa were present among litter fauna (Table 7). The predominant share of termites (Table 8) made diversity in macrofauna low.

Typical representatives of forest animals were those with a weak cuticle; these are sensitive to desiccation and include Thysanura, Protura, Symphyla, Acaridida and Oribatid mites of the families Mesoplophoridae, Hypochthoniidae and Phyllochthonidae. The presence of Uropodina and the Oribatid families Plateremaeidae and Oppiidae was indicative of a heterogeneous pore system with many cavities, and the presence of 50 different species of mainly fungivorous Oribatid mites reflected the diversity in trees and decomposing fungi.

Mesofauna were mostly found in the uppermost 2.5 cm. This layer was also highest in crude and soil organic matter and in porosity (Fig. 11), suggesting that these factors were related to the number of animals.

Table 7. Number of animals and taxa of litter fauna and soil fauna. Kabo forest.

	Litter fauna	Soil fauna	
		meso	macro
Number of sample sites	4	10	8
Depth, cm	5-0	0-20	0-15
Number of animals, m^{-2}	13 640	85 000	4 810
dm^{-3}	267	425	32
Number of taxa, m^{-2}	98	56	34
Ratio H'/H' max[a])	0.68	0.78	0.30

[a]) Relative diversity index H'/H' max, according to Shannon-Weaver (Poole, 1974; Peet, 1975).

Table 8. Number of animals in major groups, per 1000 animals of litter fauna and soil fauna. Kabo forest.

Scientific name	English name	Litter fauna	Soil fauna	
			meso	macro
APTERYGOTA	Apterygotes			
Thysanura	Bristletails	1	1	0
Diplura	Japygids, etc.	2	19	4
Protura	Proturans	0	66	0
Collembola	Springtails	44	185	1
INSECTA	Insects			
Orthoptera	Crickets, etc.	0.2	0	0.4
Isoptera	Termites	9	10	781
Psocoptera	Dust-lice	0	4	0
Homoptera	Cicadas, etc.	1	0	0
Heteroptera	Bugs	1	1	0.4
Thysanoptera	Thrips	5	0	0
Lepidoptera	Caterpillars	1	0	0.4
Diptera	Flies + maggots	14	12	4
Hymenoptera	Wasps (excl. ants)	1	0	0
Formicoidea	Ants	55	36	58
Coleoptera	Beetles + larvae	9	6	14
CRUSTACEA	Wood lice, etc.	1	6	7
MYRIAPODA	Myriapods			
Diplopoda	Millipedes	10	7	14
Chilopoda	Centipedes	0.2	1	12
Pauropoda	Pauropods	1	35	0
Symphyla	Symphilids	0.5	38	5
ARACHNIDEA	Arachnids			
Scorpionida	Scorpions	0.2	0	1
Araneida	Spiders	8	5	4
Schizomida	Whipscorpions	0.2	0	0
Pseudoscorpionida	Pseudoscorpions	5	1	2
Ricinuleida	Ricinoidids	0	1	0
ACARIDA	Mites			4
Parasitiformes	Predatory mites	0	0	0
Gamasina		107	204	0
Uropodina		151	26	0
Actinedida	Prostigmatid mites	5	13	0
Oribatida	Beetle mites			
Macropylides		264	138	0
Brachypilides				
Apterogasterina		128	84	0
Pterogasterina		170	37	0
Acaridida	Astigmatid mites	0.2	54	0
MOLLUSCA	Snails	0	0	0.4
OLIGOCHAETA	Earthworms, potworms	0	1	88
NEMATODA	Threadworms	4	1	0

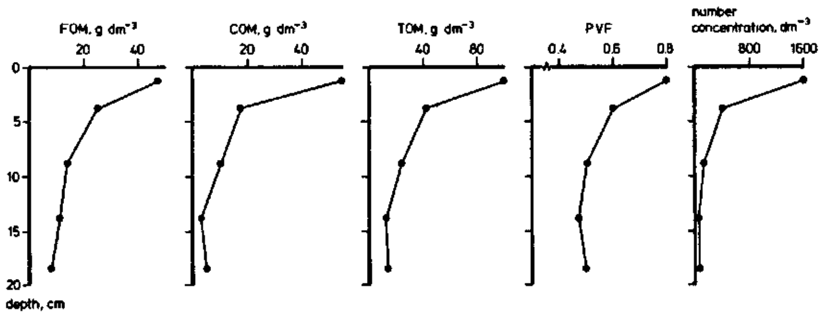


Fig. 11. Mass concentration of fine organic matter in soil (FOM), crude organic matter (COM) and total organic matter (TOM), volume fraction of pores (PVF) and number concentration of mesofauna animals in relation to soil depth.

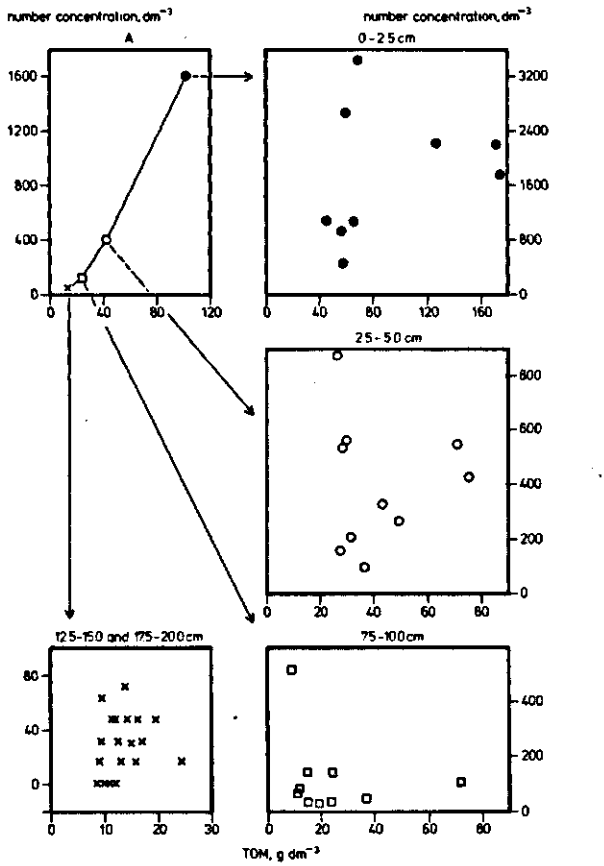


Fig. 12. Relationships between the number concentration of mesofauna animals and total organic matter (TOM). Soil layer averages (A) and values of individual samples for the soil layers indicated.

The average values of the number of animals per soil layer were indeed related to the average values of soil organic matter (SOM), crude organic matter (COM), total organic matter (TOM) and pore volume (PVF). In Fig. 12 (top left) this is shown for the relation between number of animals and total organic matter. However, no clear relationships were found for the individual soil layers (Fig. 12). Although all factors decreased with depth, their mutual relationships, if any, were weak. The numbers of animals at a total organic matter content of 60 g dm^{-3} were approximately 1000, 400 and 100 for the layers 0-2.5, 2.5-5.0 and 7.5-10 cm, respectively. The number of animals seems to depend more on the distance from the soil surface than on the amount of organic matter or the pore volume.

5 From forest to arable land

5.1 Clearing

The discussion on clearing refers to Kabo only, as the Coebiti Experimental Farm was already in existence when the present project started (Section 2.3). Various activities were undertaken to convert the forest into arable land:

- removal of valuable timber;
- felling, by machines or by hand;
- piling (only mechanically), before or after burning;
- burning, before or after piling;
- soil preparation for planting.

The operations of felling, piling and burning together comprise clearing.

Twenty-one ha were cleared mechanically and 4 ha were reserved for clearing by hand.

5.1.1 Removal of valuable timber

The site selected for Kabo Experimental Farm was located in an area of unexploited forest (Section 4.1). Before clearing operations started, the valuable timber was removed by a local logging company using methods that are standard in the region. Trees were felled with a chain saw, leaving 1-1.5 m high stumps. The crown was cut off at a length such that a useful stem remained. The stems were extracted with a skidder. Usually, these machines make their own tracks through the vegetation when picking up stems and pulling them out of the forest. Whenever possible, the skidders travel along existing tracks, thus creating so-called skidder roads that eventually lead to an existing forest road.

In the case of Kabo, however, the skidder roads were planned to be outside the farm area or to coincide with the boundaries of the farm. About 300 stems were removed from a total area of 25 ha, which was only about half of the commercially valuable trees present. The remainder apparently did not meet the quality standards set by the logger.

5.1.2 Mechanical clearing

The mechanical clearing was done with a bulldozer equipped with a tree pusher. The machine was a model D8K Caterpillar with a rated flywheel power of 224 kW and a weight of 31.7 tonnes. As the bulldozer was in poor condition it most probably did not meet the flywheel power specifications.

The light undergrowth including small trees was pushed aside with the bulldozer's blade so that the large trees would fall in a relatively open area. Large trees were pushed over with the tree pusher. Most of the roots of very large and well-anchored trees such as bullet wood (*Manilkara bidentata*), had to be cut before the trees could be uprooted. A large hole was dug at the base of these trees, and the roots were cut with the edge of the bulldozer blade. A similar procedure was followed to uproot the stumps left after exploitation. Such uprooting severely damaged the soil.

The entire felling operation was completed in the period between 18 September and 24 October 1978 when the weather was rather dry.

As preparation for the planned agricultural trials 13 ha were burnt before piling (windrowing), whereas on the remaining 8 ha the felled vegetation was burnt after piling, i.e. in the windrows. Burning before piling was not complete. The dry leaves and small branches burnt up rapidly before the larger branches and stems caught light. When this material that had been burnt once, was piled the resulting windrows proved difficult to ignite because of a lack of light material that acts as kindlings. The windrows consisting of unburnt debris burnt much better and more completely. Nevertheless, as most trees belonged to hardwood species many stems and root systems remained in the windrows after burning.

Piling was done with the same bulldozer and blade used for felling, even though the contract stipulated that a rake should be used. The debris was piled up in windrows 45-50 m apart. An attempt was made to avoid disturbing the topsoil during piling. As a result, much wood was left behind on the soil. A second windrowing was necessary to remove this material.

The windrowing operations were carried out in the period mid-November 1978 – early May 1979, interrupted by many mechanical breakdowns and rainfall. In principle, work was stopped when the field was wet, but in practice this proved to be difficult. Moreover, when general conditions appeared to be reasonable, the depressions where trees had been uprooted were still wet. The heavy, soil-clogged rooting systems that mostly lay next to such depressions were difficult to move. Their removal caused extra difficulties on a wet soil, leading to much soil damage.

From time studies it was found that it took 4 hours and 47 minutes to fell

Table 9. Results of time and motion studies on clearing tropical rainforest at Kabo with a Caterpillar D7 crawler tractor, carried out in July and November 1979.

Activity	Time required		Estimated speed	Distance
	$h\ ha^{-1}$	%	$km\ h^{-1}$	$km\ ha^{-1}$
felling, tree pusher	0.90	7.2	1.2	1.080
felling, blade	0.92	7.4	2.2	2.024
cutting roots	0.11	0.9	1.2	0.132
piling (with rake)	4.85	38.9	1.7	8.245
idle travelling	5.35	43.0	3.8	20.330
miscellaneous (stops, etc.)	0.32	2.6		
total	12.45	100		31.811

one hectare, whereas windrowing required 3 hours and 23 minutes. These times were respectively 40 per cent and 8 per cent more for felling and for windrowing than calculated from the formulas of Rome Industries (Anon., 1977).

More detailed studies were carried out in two 2.9-ha plots, adjacent to Kabo Experimental Farm, in July and November 1979 (Table 9). Felling and windrowing were done in one operation. The number of machine hours per hectare for the total operation was 11.1 in July and 13.8 in November. Forty-three per cent of the time was taken up by idle travelling. It was calculated that the bulldozer with a shoe width of 1.02 m passed over the area 3.1 times.

5.1.3 Soil preparation following clearing

After windrowing, the fields were very uneven, many depressions were present and the soil was still covered with many smaller branches and roots. Some levelling was achieved by passing over the fields a number of times with a disc harrow behind an agricultural tractor. After each pass the pieces of wood were collected and removed by hand. Fields that were to be planted to kudzu, Crotalaria or grass were disc harrowed once and only the larger pieces of wood were removed. The crops were sown with an old seed drill. On the fields where experiments were to be started shortly, a cultivator with spring-mounted tines was used after disc harrowing, thus bringing buried pieces of wood to the surface. Thereafter standard tillage practices were employed, but after each ploughing the wood remnants that came to the surface were collected. No exact data are available on the labour required for wood removal, but it amounted to several man-days per hectare.

The standard tillage operations, especially power harrowing, produced a good levelling. The depressions in the field decreased with each cropping cycle. However, during the earliest cropping cycles there were many bad spots in the field, especially during the rainy seasons. The slightest depressions collected rain water, resulting in local waterlogging.

The strategy chosen was intended to minimize topsoil disturbance. However, it is debatable whether levelling with a scraper or land plane immediately after clearing might not have been a better practice.

Large windrows of partly burnt stems and soil-clogged root systems were still present one year after felling. In November 1979, 2100 m of windrows were moved over a distance of about 45 m to increase the size of the fields. This led locally to heavy compaction of wet soils. The work required 49 machine hours of a 224-kW bulldozer.

5.1.4 Clearing by hand

Clearing by hand comprised the following steps:
- cutting the light vegetation with a bush knife;
- cutting the smaller trees (diameter less than 40 cm) with an axe 25 cm below ground level;

– felling the larger trees with a chain saw about 1 m above ground level.

It was difficult to contract labourers to do the clearing by hand. As a result, progress was so slow that the work was stopped after 2 ha had been cleared. The net time required to remove the trees with a diameter less than 40 cm was already 474 man-hours per ha. Allowing for rest, etc. this comes to 800 man-hours per ha for this part of the clearing. The high cost of labour in Suriname makes clearing by hand much more expensive than mechanical clearing. Moreover, after hand clearing large stumps are left in the field, rendering mechanized farming very difficult if not impossible.

On 1 ha the felled vegetation was burnt in situ. Burning was repeated several times; between burns the smaller unburnt pieces were stacked by hand. The larger pieces that remained unburnt were eventually winched out and burnt outside the plot. The ashes on the plot were distributed by hand. On the other hand-felled hectare no burning took place. As a result the natural vegetation regenerated very rapidly and six months later the plot had become virtually inaccessible. This plot was never used for field experiments.

5.2 Changes in soil characteristics

5.2.1 Physical soil characteristics

Soil structure can be severely damaged by mechanical clearing, especially by windrowing. At Coebiti and Kabo it was found that soils could be compacted up to 70 cm and deeper (Fig. 13). By comparison, hand clearing gave rise to only a slight compaction, limited to the upper 20 to 30 cm. The main cause

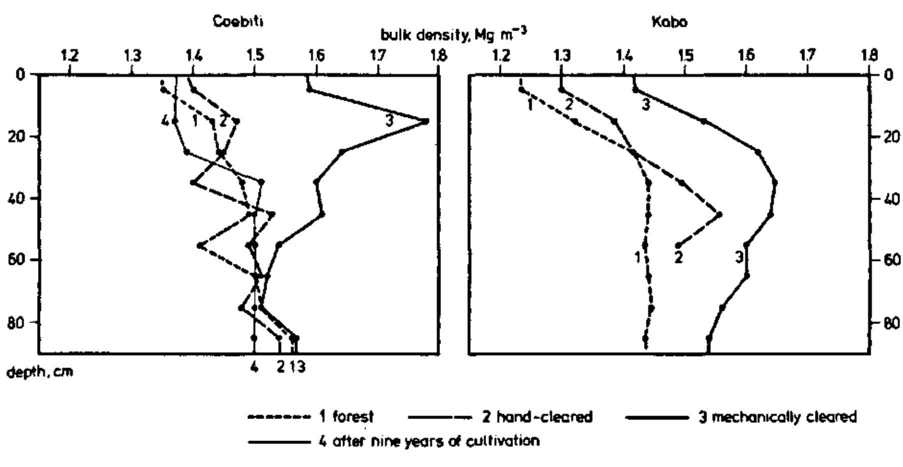


Fig. 13. Effects of different clearing methods and of cultivation on bulk density profiles of sandy-loam and loam soils at Coebiti and Kabo. Data from Coebiti (Curves 1, 2, 3) after Van der Weert & Mahesh (1972b).

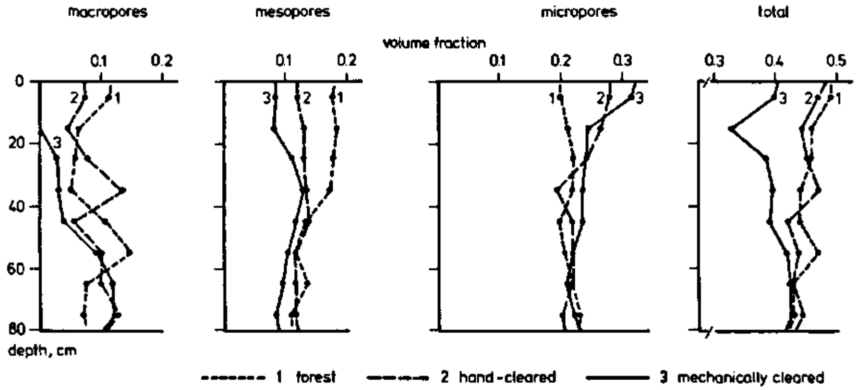


Fig. 14. Effect of clearing on volume fraction of macropores, mesopores, and micropores and on total porosity for a sandy loam of Coebiti. After Van der Weert & Mahesh (1972b).

for this decrease in porosity might have been exposure to rain in combination with loss of organic matter and decrease in biological activity.

Van der Weert (1974) and Van der Weert & Mahesh (1972b) showed that compaction caused the macro- and mesopore volume to decrease, and the micropore volume to increase (Fig. 14). This means that the volume fraction of soil moisture at field capacity increased slightly upon compaction. However, root permeability and aeration could decrease to such an extent that root growth was severely impeded.

It is difficult to conclude from Fig. 13 whether Coebiti and Kabo soils were equally susceptible to compaction, because bulk densities varied strongly over short distances. Generally, compaction was most severe at depths between 10 and 30 cm at Coebiti and between 30 and 50 cm at Kabo. In practice the Kabo soils appeared more difficult to cultivate than the Coebiti soils, the main problem being that soils remained too wet for long periods. One of the reasons for this difference might be that Coebiti soils had already recovered during the years of cultivation preceding the present project, and Kabo soils had not (Fig. 13, curve 4). A second explanation might be a difference in free iron content (Fig. 15). This difference was established in a mineralogical and rheological study and might indicate that Kabo soils have a lower aggregate stability because they contain fewer stable complexes of clay, iron and organic matter than Coebiti soils. In both soils b-axis disordered kaolinite proved the main clay mineral, with lateral and vertical dimensions of 0.5 and 0.02 μm, respectively, which is smaller than normal (Blok, 1983). This clay mineral is unstable, having more or less rounded edges, instead of the characteristic straight sides and right angles.

Compaction not only caused rooting problems, it also severely reduced water infiltration rates, resulting in waterlogging in small depressions and runoff and erosion on slopes. During dry periods compacted areas were more drought

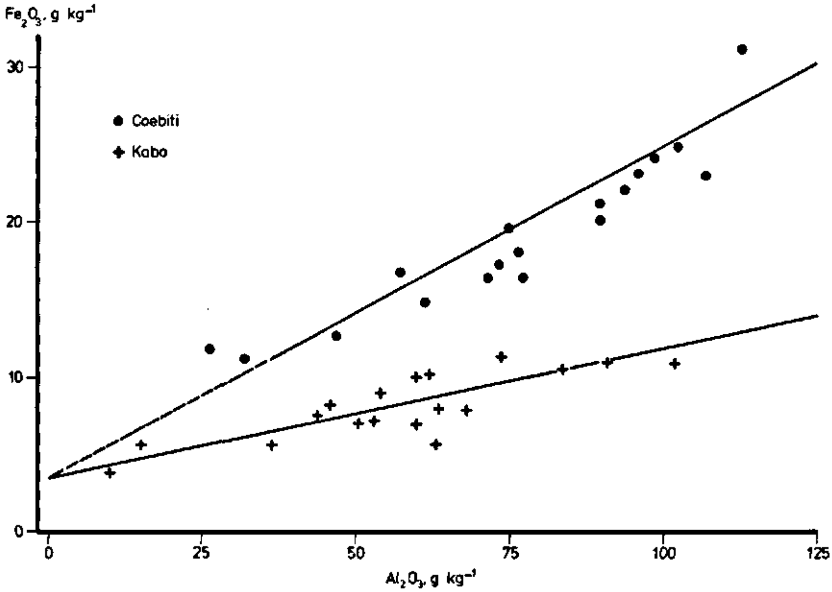


Fig. 15. Relationships between mass fraction of free iron and mass fraction of aluminium for Coebiti and Kabo soils (Blok, 1983).

sensitive. Machine operations have to be delayed when soils are too wet, and this also delays tillage and planting (Section 8.2).

Compaction was most severe when clearing and windrowing took place under wet conditions (puddling). Clearly, mechanical clearing should be done in the second half of the long dry season only and heavy machinery should be avoided as much as possible. After the trees have been uprooted evapotranspiration is reduced and it takes a long time for a bare soil to dry out.

Probably the best method of clearing is to allow the felled vegetation to dry. After burning, a cover crop can be established to extract soil moisture and reduce leaching of nutrients. As a consequence, windrowing must be postponed until the next dry season. In practice, however, this is not always possible and postponement seems loss of time. On the other hand it will take many years of cultivation before soils have recovered from compaction.

5.2.2 Chemical soil characteristics

The extent to which soil chemical properties changed upon clearing depended on the methods used and the conditions during clearing. Short-term and long-term effects could be distinguished.

Table 10. Chemical properties of topsoils (0-20 cm) before (BC) and after clearing (AC) for different clearing methods[a]). Kabo.

	BC	AC	BC	AC	BC	AC	AC
Clearing method		A		B		C	D
Months after felling		7		2.5		11	14
Months after burning		n.a.[b])		1.5		n.a.	4.5
Months after windrowing		3		n.a.		n.a.	n.a.
Number of samples	13	13	7	7	9	8	9
Organic C, g kg^{-1}	11.3	11.8	11.8	12.7	13.3	11.8	13.3
Organic N, g kg^{-1}	0.8	0.7	1.0	1.0	0.9	0.8	0.8
C/N, g g^{-1}	14.1	16.9	11.8	12.7	14.8	14.8	16.6
P-Bray-I, mg kg^{-1}	2.9	4.8	1.1	6.8	2.9	4.5	8.0
pH(KCl)	3.6	3.8	3.5	4.6	3.8	3.7	4.9
pH(H_2O)	4.2	4.5	4.2	5.3	4.4	4.2	5.6
CEC[e])	28.2	32.9	33.5	39.3	40.7	32.1	n.d.[c])
Ca	2.9	2.9	1.8	16.6	1.3	3.3	22.8
Mg	1.1	0.5	1.1	4.6	0.9	0.9	3.3
K	0.3	0.5	0.3	2.2	0.3	0.4	2.1
Na	0.2	0.1	0.1	1.3	0.2	n.d.	0.5
Sum of bases	4.5	4.0	3.3	24.7	2.7	4.8[d])	28.7
Al	5.1	9.9	11.2	5.3	13.9	11.4	3.9
ECEC	9.6	13.9	14.5	30.0	16.6	16.2	32.6

[a]) A: mechanical clearing; burning after windrowing.
B: mechanical clearing; in situ burning of debris; ashes removed from sampling place.
C: hand clearing; not burnt.
D: hand clearing; repeated burning; ashes redistributed.
[b]) n.a. = not applicable.
[c]) n.d. = no data available.
[d]) Including an assumed quantity of exchangeable Na of 0.2 mmol kg^{-1}.
[e]) CEC and exchangeable cations: ionic equivalents, mmol kg^{-1}.

5.2.2.1 Short-term effects

In Table 10 and Fig. 16 chemical soil data from fields cleared according to the four systems described in Section 5.1 are compared with the data from samples taken in the same area before clearing. These averaged data do not show how heterogeneous the soils were. The natural heterogeneity was aggravated by irregular movements of topsoil during felling and windrowing, by an uneven intensity of burning and an uneven distribution of ashes. Generally, pH, exchangeable cations and related characteristics, and P-Bray-I were higher after clearing than before, the differences having been caused by the release of nutrients from the felled vegetation. For this release burning was much more important than mineralization. Where the felled vegetation had been piled before burning (Method A in Table 10), only P-Bray-I increased. Any cations released by mineralization had probably already been leached from the topsoil. More nutrients were released by repeated burning after felling by hand (Method D) than with the

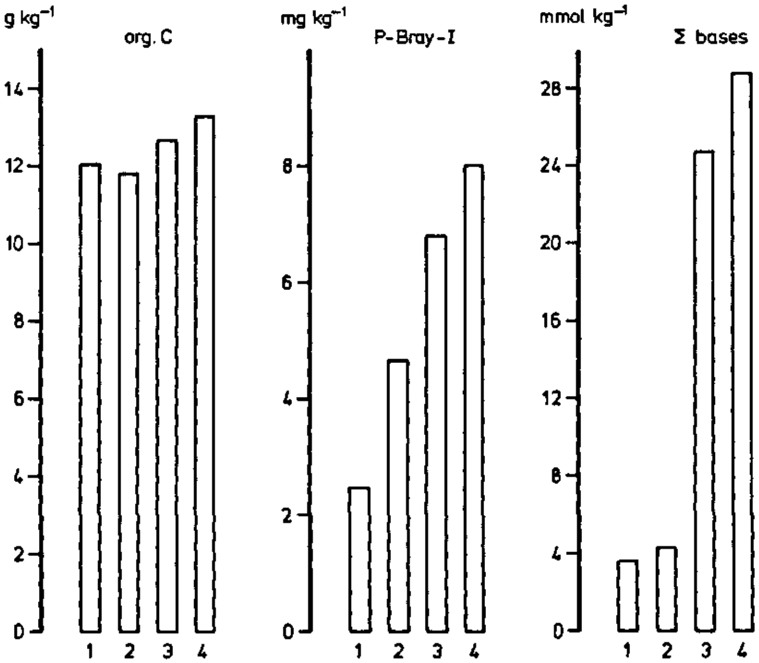


Fig. 16. Average values of organic C, P-Bray-I and sum of ionic equivalents of exchangeable bases of topsoils (0-20 cm). 1 = under forest, 2 = after felling before burning, 3 = 1.5 months after burning, ashes removed, 4 = 4.5 months after clearing, ashes redistributed.

other methods. The larger release of nutrients was of little advantage, because soils were unable to retain the released nutrients, except for P (Table 11). One month after burning, ash samples were taken for analysis from the area where burning had been incomplete. The amount of ash per ha was estimated to be roughly 10 tonnes, and ranges of nutrient mass fractions were 4.9-15.5 g kg^{-1} for N, 0.3-0.9 g kg^{-1} for P, 1.2-7.3 g kg^{-1} for K, 8.5-22.0 g kg^{-1} for Ca and 1.2-7.4 g kg^{-1} for Mg. Average amounts of nutrients in ash proved to be only 2-11 per cent of the amounts present in aboveground living phytomass plus litter (Table 11, Rows 2 and 3). A larger portion was found in the topsoil at that time (Rows 6 and 8), indicating a rapid washing of nutrients from ash into soil. The theoretically maximum amounts of cations that could be retained by the topsoil (Row 5) were calculated by assuming a maximum CEC of 35 mmol kg^{-1} and a relative Ca:Mg:K:Na distribution of 65:20:10:5 (the rounded averages of the data in Table 10). According to these estimates soils should theoretically be able to retain 26-72 per cent (Row 7) of the nutrients present in the living phytomass and litter. In fact, retention was about two-thirds of this maximum one month after burning (Rows 6 and 8).

From these data it can be concluded that any increase in soil fertility caused

Table 11. Estimated amounts of nutrients (kg ha^{-1}) present in living phytomass and litter, in ashes and in topsoil (0-20 cm) under forest, at theoretical maximum, and after burning. Kabo.

	N	P	K	Ca	Mg
A. Living phytomass + litter[a])	1 709	112	1 313	2 861	270
B. Ashes, 1 month after burning	100	5	31	145	30
C. 100 × B/A[b])	6	4	2	5	11
Topsoil[c])					
D. under forest[d])		3.0	32	108	33
E. at theoretical maximum[e])			369	1 229	227
F. 1 month after burning[d])		18.4	232	896	149
G. 100 × (E-D)/A			26	39	72
H. 100 × (F-D)/A		14	15	28	43
L. C + H		18	17	33	54

[a]) Phytomass without roots, from Table 6.
[b]) Letters refer to parameters represented by other rows.
[c]) Volumic mass assumed at 1.35 Mg m^{-3}.
[d]) From Table 10; for P values based on P-Bray-I.
[e]) For explanation see text.

by an extra release of more nutrients in the case of a more complete burning would have been shortlived.

Nutrient leaching is discussed further in Sections 6.4 and 6.5

5.2.2.2 Long-term effects

Irrespective of whether burning was in situ or in the windrows, soil fertility was very irregular during the first years after clearing. Apart from the temporary effects of ashes in the case of in-situ burning, there were differences over short distances because in some places surface soil had been removed or had accumulated and in others subsoil had been mixed with the topsoil when large trees were uprooted. Small depressions often remained where trees had been uprooted; they became waterlogged during the rainy seasons.

In 1972-73, i.e. three years after clearing the Coebiti forest, it proved almost impossible to find areas larger than 5 m^2 with a uniform growth of maize (Janssen & Van der Weert, 1977). The soil property most strongly related to yield was soil organic matter, and this property is especially liable to change with movements of subsoil and topsoil.

Soil tillage, fertilizer applications and the removal of nutrients by crops and by leaching gradually reduced heterogeneity in soil fertility. Fig. 17 shows that pH(KCl) and exchangeable cations varied less at Coebiti after 12 years of continuous cropping than at Kabo three years after clearing. The soil samples were from fields used in a similar trial at both stations. Coebiti and Kabo had very similar mean values for pH(KCl) (4.84), ionic equivalents of exchangeable Ca (20 mmol kg^{-1}) and K (1.25 mmol kg^{-1}). At Kabo the chemical soil properties shown in Fig. 17, were strongly mutually correlated, whereas at Coebiti the only

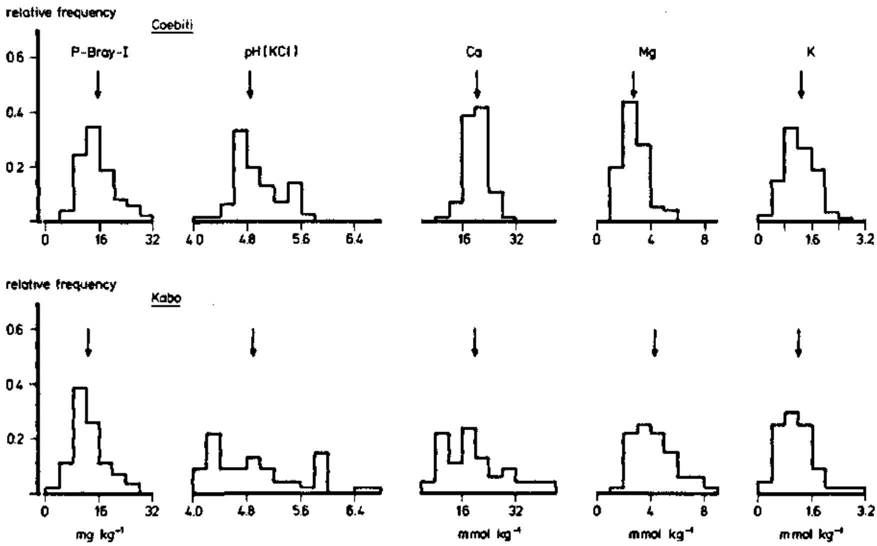


Fig. 17. Relative frequency distribution of P-Bray-I, pH(KCl) and ionic equivalents of exchangeable cations (0-20 cm) at Coebiti, 12 years after clearing, and at Kabo, 3 years after clearing. Coebiti: 108 plots of 22.5 m^2 each. Kabo: 54 plots of 18 m^2 each. Arrows indicate average values.

significant correlation found was between pH(KCl) and exchangeable Ca. This suggests that ashes still had an influence on chemical soil properties three years after burning. Also the fact that the mean value for exchangeable Mg was higher at Kabo than at Coebiti (4.25 vs 2.81 mmol kg^{-1}) points to ash influences at Kabo.

In Section 6.5.3 it is shown that P-Bray-I gradually increased with time when P fertilizer had been applied. This might explain why P-Bray-I was slightly higher at Coebiti (Fig. 17) than at Kabo (15 vs 13 mg kg^{-1}) in spite of the ash influence at Kabo.

A longer lasting effect existed on the sites of former windrows. Here accumulation of topsoil and repeated burning of wood and root remains had led to an increase in soil fertility that was still visible eight years after the windrows had been pushed aside, though less markedly than in the first year (Table 12). The only value that was not higher inside than outside the former windrow was P-Bray-I; both areas had received the same amount of fertilizer phosphorus but crop growth was better in the site of the former windrow and therefore more phosphorus was taken up there than in the area outside. The windrow effect on calcium and magnesium should probably be attributed to a concentration of topsoil which resulted in an increase in organic matter and consequently in an increased capacity to retain cations. The deeper topsoil was probably the main cause of the better crop growth on the former windrow.

Table 12. Effects of a former windrow on soil properties (in 1980) and yields. Area was cleared in 1969 and windrow was pushed aside ca. 1972. Coebiti.

Soil properties (0-20 cm)			Yields, t ha^{-1}		
	control	former windrow	crop, year	control	former windrow
Organic C, g kg^{-1}	9.6	11.8	Maize		
P-Bray-I, mg kg^{-1}	25.5	17.0	1973	1.38	2.63
pH(KCl)	4.3	4.6	1980	1.95	2.65
CEC[a])	37.6	53.4			
Ca	9.2	18.3	Sorghum		
Mg	2.2	5.0	1973	0.60	2.43
K	0.5	0.5	1980	3.27	4.10
Al	3.3	0.4			
ECEC[b])	15.3	24.3			

[a]) CEC and exchangeable cations: ionic equivalents, mmol kg^{-1}.
[b]) For calculation of ECEC exchangeable Na was assumed to be 0.1 mmol kg^{-1}.

Soil heterogeneity, especially the windrow effect, seriously inconvenienced the layout of field trials.

5.2.3 Litter and soil fauna

It was not possible to sample litter fauna and soil fauna at the same sites. Litter fauna could only be sampled in places that were not tilled. Soil mesofauna was collected from fields where no insecticides had been used (with one exception; see below) and soil macrofauna samples were taken from fields in which soil structure was too bad for normal crop growing. Methods used for extracting animals were as described in Section 4.2.4. The results of the studies are presented for each group of animals separately.

5.2.3.1 Litter fauna

Samples were taken from an area that had been cleared mechanically, with windrowing done after burning. The sampled fields had been growing *Pueraria phaseoloides*, *Andropogon gayanus* and cassava (*Manihot esculenta*).

In Table 13 the characteristics of litter fauna present under these crops are compared with those under primary forest. The total number of litter animals was higher under *Pueraria* and cassava than under forest; it was lowest under *Andropogon*. The number of taxa did not differ much among field crops but was only about half the number in forest litter.

Cassava, being an open crop, had the thinnest litter layer, with the lowest moisture content and the highest absolute maximum temperature (recorded from December 1981 – February 1982). Consequently, animals that cannot withstand dry conditions were hardly found in cassava litter, whereas they did occur

Table 13. Some characteristics of litter and litter fauna under three permanent crops and under primary forest. Number of animals in major groups per 1000 animals, ranked in order of frequency under forest. Kabo.

		Pueraria	*Andropogon*	Cassava	Forest
Number of samples		2	2	2	4
Thickness of litter layer, mm		32	28	7	51
Moisture mass ratio to dry litter		3.22	1.43	0.50	2.18
Temperature					
absolute min., °C		18	21	21	21
absolute max., °C		37	39	49	35
Number of animals per m^2		114 528	7 672	16 219	13 640
Number of animals per dm^3		3 579	274	2 317	266
Number of taxa		51	47	55	98
100 × H′/H′max[a])		47	61	49	68
Scientific name	English name				
Macropylides	Beetle mites	148	32	382	264
Brachypylides					
Pterogasterina	Beetle mites	315	54	82	170
Apterogasterina	Beetle mites	270	61	166	128
Uropodina	Predatory mites	0	0	0	151
Gamasina	Predatory mites	118	8	100	107
Formicoidea	Ants	2.3	0.6	2	55
Collembola	Springtails	73	206	146	44
Diptera	Flies + maggots	3	15	8	14
Diplopoda	Millipedes	15	31	17	10
Coleoptera	Beetles + larvae	16	63	51	9
Isoptera	Termites	0	0	0	9
Thysanoptera	Thrips	8	447	5	5
Chilopoda	Centipedes	0	0	2	0.2
Protura	Proturans	10	3	0	0
Oligochaeta	Earthworms, potworms	1	4	0.1	0

[a]) Relative diversity index. See note to Table 7.

in *Pueraria* litter which has a high moisture content and a not too extreme absolute maximum temperature. They comprised Entomobryid springtails, Proturans and earthworms. On the other hand, certain surface-dwelling, drought-resistant taxa such as centipedes and some beetle families (Staphylinidae, Ptiliidae) were often encountered in the litter of cassava, but seldom in that of *Pueraria*.

Brachypilid beetle mites were the dominant group in the crop litter. Under forest they share their role in wood and litter decomposition with termites, but termites were absent under the crops. The fungivorous Uropodid mites were also found only in forest litter. An important role in the decomposition of crop litter is played by the Collembola; they live off fungi and bacteria associated with decaying litter, carrion and faeces.

Many thrips (Thysanoptera, family Phlaeothripidae) were found in *Andropogon* litter. This group predates or feeds on fungi.

Table 14. Some characteristics of soils and of mesofauna under crops and under primary forest. Number of animals in major groups per 1000 animals, ranked in order of frequency under forest. Sampling depth 0-20 cm. Kabo.

		Cleared by hand		Mechanically cleared				Primary forest
		cultiv. depth 5 cm		cultivation depth 5 cm			25 cm	
		cassava	soybean	maize	cassava	soybean	soybean	
Number of samples		5	5	5	5	5	5	10
Organic C, $g\ kg^{-1}$		7.3	8.4	7.0	8.0	8.3	10.9	11.5
Bulk density, $Mg\ m^{-3}$		1.40	1.32	1.24	1.35	1.35	1.35	1.20
Number of animals per m^2		52 900	25 500	84 900	27 800	82 800	55 800	85 000
Number of taxa		30	25	29	21	26	24	56
$100 \times H'/H'max$ [a])		29	76	75	43	69	35	78
Scientific name	English name							
Collembola	Springtails	608	358	215	50	220	752	185
Gamasina	Predatory mites	165	181	272	427	375	167	204
Uropodina	Predatory mites	0	0	0	0	0	0	26
Macropylides	Beetle mites	14	31	133	113	139	6	138
Brachypylides	Beetle mites	93	35	160	192	130	6	121
Acaridida	Astigmatid mites	12	75	0	0	0	6	54
Symphyla	Symphilids	0	66	0	0	0	0	38
Formicoidea	Ants	8	58	4	8	6	0	36
Pauropoda	Pauropods	125	49	168	42	75	7	35
Isoptera	Termites	0	22	0	0	0	0	10
Coleoptera	Beetles + larvae	20	75	10	38	11	15	6
Oligochaeta	Earthworms, potworms	2	13	0	0	0	2	1
Nematoda	Threadworms	0	0	0	0	0	0	1

[a]) Relative diversity index. See note to Table 7.

5.2.3.2 Soil mesofauna

Samples were taken from six sites. Two sampling sites were located in an area cleared by hand, cultivated to 5 cm and continuously grown with cassava and soybean. The other four were in mechanically cleared fields. Three of these fields had been cultivated to a depth of 5 cm and continuously grown with maize, cassava and soybean. The fourth field had been ploughed 25 cm deep and grown with soybean in rotation with maize; pesticides had been used.

The number of animals decreased in the order primary forest > mechanically cleared > cleared by hand, and for mechanically cleared fields in the order maize > soybean > cassava (Table 14). The number of taxa decreased upon clearing; but method of clearing and type of crop were of indistinct influence. The relative diversity index, indicating frequency distribution, decreased for soybean in the order cleared by hand > mechanically cleared + 5 cm tillage > mechanically cleared + 25 cm tillage. This index was low for cassava, reflecting the extreme microclimate under this crop.

Under crops soil porosity and total organic matter (TOM) decreased with depth but not as sharply as under forest, especially not when the soil had been ploughed to 25 cm (Fig. 18). Similarly, the decrease with depth in the number of animals was not as sharp under crops as under forest; under crops most animals tended to dwell in the 2.5 – 5 cm soil layer. The microclimatic conditions in the uppermost layers of cultivated soils, which were not protected by litter, apparently forced the animals to live in deeper layers.

Although the relationships between total organic matter and the number of animals are rather weak (Fig. 19), it seems justified to conclude that per gram of total organic matter the more readily digestible crop residues could support more animals than the woody residues under forest. At a depth of 2.5 – 5 cm under primary forest the mesofaunal biomass was 700 mg dry weight per m^2 at a TOM of 4.5 per cent (55 g dm^{-3}). In maize this biomass was 1100 mg m^{-2}

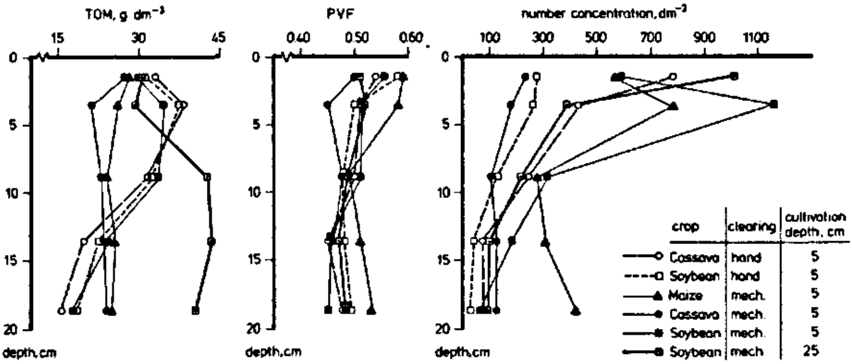


Fig. 18. Mass concentrations of total organic matter (TOM), volume fraction of pores (PVF), and number concentration of mesofauna animals in relation to soil depth, for different crops and management units.

Table 15. Some characteristics of soils and of soil macrofauna under *Pueraria*, grasses, fallow and primary forest. Number of animals in major groups per 1000 animals, ranked in order of frequency under forest. Sampling depth 0-15 cm. Kabo.

		Pueraria	*Andropogon*	*Brachiaria*	Fallow	Primary forest
Number of samples		7	7	7	7	7
Organic C, g kg^{-1}		10.9	8.7	9.9	7.8	9.9
Bulk density, Mg m^{-3}		1.38	1.42	1.36	1.36	1.15
Max. penetrometer reading MPa (0-25 cm)		2.0	3.3	3.0	1.1	1.0
Number of animals per m^2		2267	1530	1574	2276	6183
Number of taxa		28	16	22	25	34
$100 \times H'/H'max$[a])		55	51	53	31	31
Scientific name	English name					
Isoptera	Termites	166	3	0	0	805
Oligochaeta	Earthworms, potworms	417	413	265	36	81
Formicoidea	Ants	45	420	151	855	41
Coleoptera	Beetles + larvae	27	15	22	52	15
Symphyla	Symphilids	0	115	517	0	6
Diplura	Japygids, etc.	284	0	0	0	3

[a]) Relative diversity index. See note to Table 7.

at a TOM of 2.4 per cent (21 g dm^{-3}) (Van der Werff, 1983).

In conclusion, mesofauna was present where soil conditions and food supply were favourable. The presence of soil mesofauna is an indication of good physical soil properties, but its absence does not necessarily mean that these properties are poor.

5.2.3.3 Soil macrofauna

Samples were taken from sites where the soil had been severely compacted by mechanical clearing, resulting in poor crop growth. One field had been fallow for two years, after having been cropped with maize and soybean. The other fields had been under *Pueraria* (for 3 years), *Andropogon* (for 2 years) and *Brachiaria decumbens* (for 3 years).

The numbers of animals and taxa in all fields were lower than under primary forest and decreased in the order *Pueraria* ≈ fallow > *Brachiaria* > *Andropogon* (Table 15).

Termites, the predominant group under forest, were found only under *Pueraria*. Ants were dominant in fallow land; earthworms, feeding on fresh organic materials, predominated under grasses and to a somewhat smaller extent under *Pueraria*. Diplura were common under *Pueraria* and Symphyla under grasses.

No clear relationships were found between the number of animals and either soil organic carbon, bulk density or penetrometer readings. The values for bulk density were normal for forest and mechanically cleared land (cf. Fig. 13). The low penetrometer readings under fallow were probably a result of previous ploughing.

The data do indicate that *Pueraria* is an interesting cover crop for soil restoration. The data on bulk density suggest that the activities of soil mesofauna are mainly restricted to maintaining the pore system rather than to forming new pores.

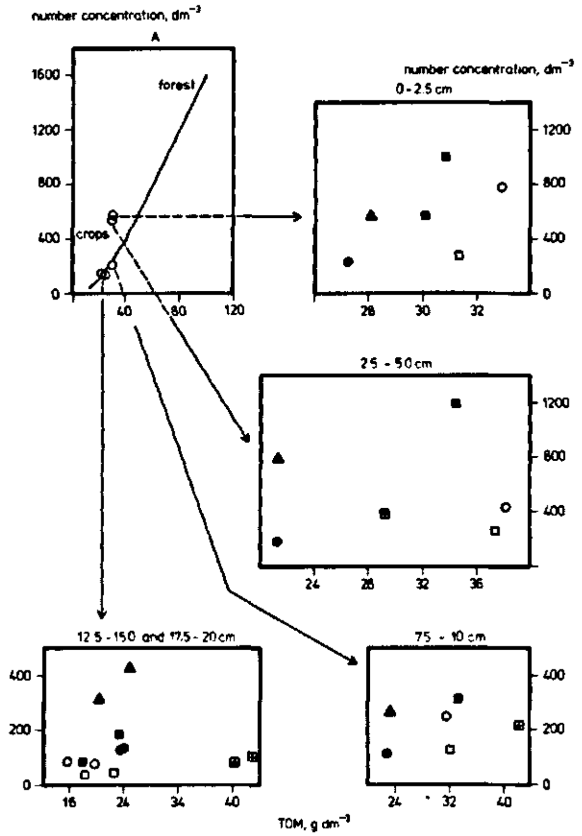


Fig. 19. Relationships between the number concentration of mesofauna animals and mass concentration of total organic matter (TOM). Soil layer averages (A) and values of individual crop and management units for the soil depths indicated. For key to symbols see Fig. 18.

6 Yields and yield-determining factors

The range in crop yields obtained in the various trials carried out in the project was very wide. This was partly because of the experimental treatments and partly a result of differences in weather conditions. To clarify the large variation in yields, first the effects of weather conditions (mainly rainfall and sunshine) are discussed (Section 6.1) before the individual growth factors and cultural practices that can affect yield are dealt with.

6.1 Potential and actual yields

6.1.1 Theoretical potential yields and water-limited yields

Plant growth requires energy, carbon dioxide, water and nutrients. They are supplied by the sun, the atmosphere and the soil. If sufficient data are available on weather, soils and crops, it is possible to use elaborate simulation models to calculate the yields that can be obtained. Such models have been developed by De Wit and his colleagues (De Wit, 1965; De Wit & Goudriaan, 1978; Penning de Vries & Van Laar, 1982; Van Keulen & Wolf, 1986). They distinguish four hierarchically ordered production situations (De Wit, 1986).

In the highest production situation, water and nutrients are in optimum supply. Crop yield is then determined only by the type of crop, the prevailing level of irradiance, and the temperature regime. This is the potential yield level.

In the second production situation, the supply of nutrients is still optimum, but for water the actual situation is considered, where water supply depends on rainfall and sometimes on supplementary irrigation. In addition to weather conditions, the physical soil properties and the degree to which the crop covers the soil are required to calculate the water balance. Via the water balance it is possible to determine periods with an excess or shortage of water, which will result in less than potential growth. The yield calculated in this way is called the water-limited yield. The gap between water-limited and potential yield can be bridged by supplementary irrigation to avoid drought, or by drainage to avoid waterlogging.

In the third production situation, plant nutrients join water and irradiance as a factor limiting growth. Nutrient supply from the soil and relations between nutrient supply, nutrient uptake and plant growth are taken into account. This yield level is called the nutrient-limited yield. The gap between nutrient- and water-limited yields can be bridged by application of fertilizers.

The fourth production situation is one where hardly any external inputs are used. The resulting yields are usually lower than the nutrient-limited ones, because of imperfect management and the occurrence of weeds, pests and diseases. Such causes of yield losses are assumed to be absent in the higher production situations.

So far, simulation models have been developed to calculate yields at the highest two levels. Because of the many factors and interactions involved at production levels three and four, no satisfactory simulation models have yet been devised. Even for the calculation of potential and water-limited yields a considerable number of crop and climatic data are required. Van Keulen & Wolf (1986) present standard values for several crop properties, but some of these values were found to be not valid for the Zanderij situation and had to be assessed from experiments in Suriname itself. The crop for which most of the required data were known was maize, thus simulation runs were made for this crop. Goense (1987) presents a full account of the adjustment of crop properties and of the way climatic data were collected and introduced in the Van Keulen & Wolf model. The climatic data used were from the meteorological station of Zanderij Airport, and covered the period 1958-1983. For the calculation of the water balance, the same assumptions were made as described in Section 6.1.3.

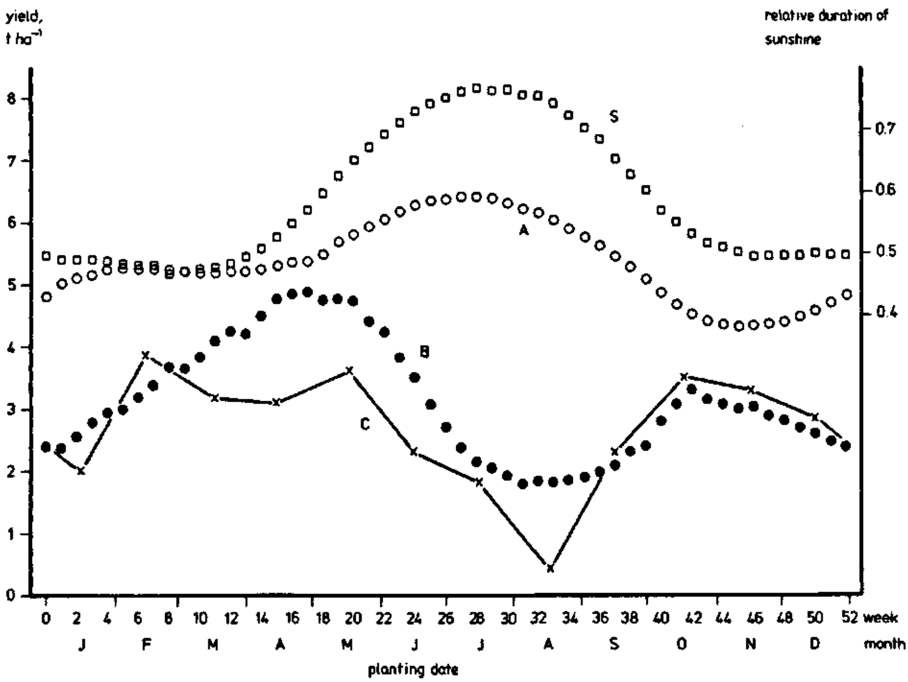


Fig. 20. Theoretical potential (Curve A) and water-limited (Curve B) maize yields, and actual yields (Curve C) in relation to planting date. Curve S: average daily relative duration of sunshine from 35 to 105 days after planting.

The main purpose of the calculations was to study the possible effect of planting date on yields, and to find the optimum growing season with regard to mechanized operations (see Section 8.2 and Goense, 1987). Irradiance, and hence potential production, may vary during the year as a result of variations in solar height and cloudiness. Water-limited yields may vary much more, because of the occurrence of dry and wet seasons (Section 3.1).

In the simulation runs, planting dates were taken throughout the year at one-week intervals. This was done for each of the years between 1958 and 1983. The results per planting date averaged over this 25-year period are presented in Fig. 20. Potential production is highest for maize planted in July. The crop can then profit from the high number of sunshine hours in September and October (cf. Fig. 4). This is demonstrated in Fig. 20 where the curves for theoretical potential yields and average relative duration of sunshine from 35 to 105 days after planting have similar shapes. Sunshine was measured between 07.00 and 17.00 h. Relative duration of sunshine is the ratio of the recorded sunshine hours to the 10 hours between 07.00 and 17.00 h.

The curve for water-limited production shows two peaks, a higher one for sowings between mid-April and mid-May, and a lower one for sowings between mid-October and mid-November. These peaks are related to the long and the short rainy seasons (cf. Fig. 2). The water-limited yields lie below the potential yields, indicating that even during the long rainy season there is some moisture stress. Water-limited yields are lowest for maize sown in August, because that crop has to contend with severe water shortage during the long dry season.

6.1.2 Actual yields in relation to planting date

The actual yields (curve C) of Fig. 20 are results from a total of 85 field trials. Only the treatments representing current cultural practices are included, i.e. ploughing, liming, fertilizer application (3 x 40 kg N, 40 kg P, 3 x 20 kg K, 25 kg FTE (fritted trace elements) ha^{-1}), crop protection measures and weed control, but no supplementary irrigation. (In the following sections these cultural practices are discussed in detail and it will be shown that in trials where other practices were applied the yields were sometimes higher.) The period covered runs from 1972 to 1982, which is only part of the time for which potential and water-limited yields were calculated. The data are from trials that had been designed for purposes other than the study of the effect of planting date on yield. As a result, the number of plantings and hence the reliability of the data is not the same for all months. Nevertheless there is a fairly good similarity between the theoretical (curve B) and the recorded (curve C) yields. The main exceptions are the April and August plantings. For the April plantings this must at least partly be attributed to the fact that the current rate of 120 kg fertilizer N per ha was too low to obtain the highest possible yields (see Section 6.6.2). Attempts to improve the fit of curves B and C by adjusting some model variables, did not remove the gap between calculated and measured yields of the August plantings (see Goense, 1987).

An important conclusion from the comparison of maize yields obtained in theoretical models and in field trials is that water availability rather than sunshine is the cause of variation in yields found for maize with varying planting dates.

The effect of planting date on yields of other crops is shown in Fig. 21. (Maize yields are included, for comparison.) For all crops it holds that the data are from trials carried out for purposes other than to study the effect of planting date. Considerably less data were available for the other crops than for maize, and in each crop data are missing for one or more months. This makes it impos-

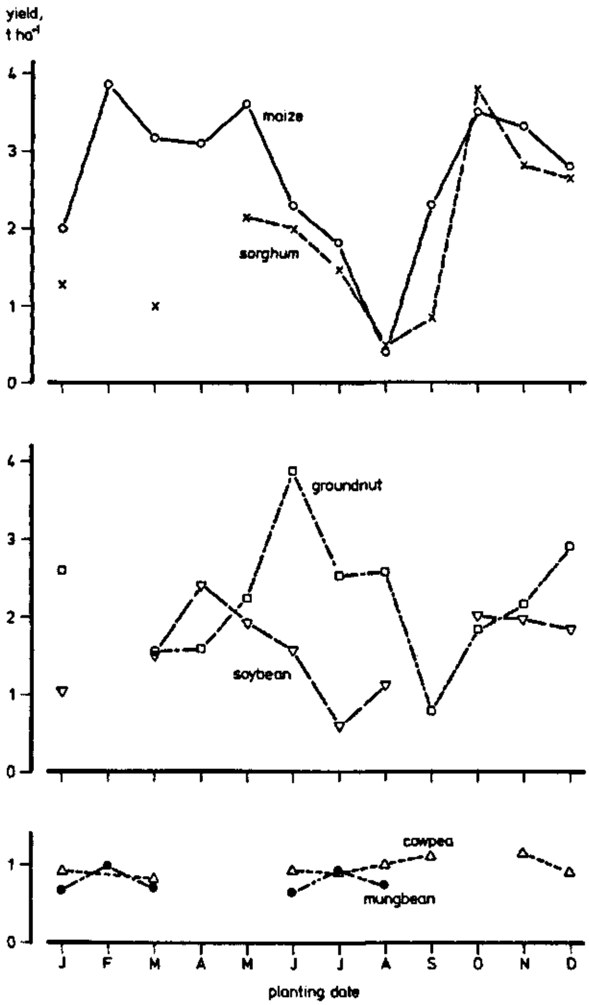


Fig. 21. Average actual yields of maize, sorghum, soybean, groundnut (pods), cowpea and mungbean in relation to planting date.

sible to draw firm conclusions. A few remarks can nevertheless be made.

The sorghum curve followed the maize curve for planting dates between May and December. Sorghum planted in January and March yielded low, because the crop then matures in the long rainy season. As ripening sorghum is extremely vulnerable to grain moulds, complete crop failures may result.

The latter also holds for soybean, whose pods are easy victims of fungal and bacterial infection under conditions of little sunshine and high humidity. The highest soybean yields were found for plantings in April and May, and October–December, i.e. about the same pattern as for maize and sorghum. These plantings hardly suffer from drought and the weather during ripening seems to be dry enough.

The highest groundnut yields were obtained for plantings in June–August (harvested in the long dry season) and in December–January (harvested in the short dry season). The data suggest that planting early in the long rainy season is not conducive to high yields. However, it must be pointed out that nearly all these yields are from experiments without adequate weed and/or disease control. These crops were affected by stem and leaf rots that are normally absent from late plantings in the long rainy season.

Cowpea and mungbean yields seemed to be hardly affected by time of planting, but there are too few data to allow conclusions to be drawn.

6.1.3 Moisture stress under rainfed conditions

In the foregoing it was shown that moisture supply rather than irradiation was the cause of the variation in yield of crops with different planting dates. The effects of moisture stress on maize yields was studied using a planting-date experiment that was started at Coebiti in June 1978. Whenever possible maize was sown twice a month for a period of just over one year. Fertilizer rates were standard : 3 x 40 kg N, 40 kg P, 3 x 20 kg K, 25 kg FTE ha^{-1}, and before planting 2 tonnes of lime (Emkal) were applied per hectare. Preventive crop protection measures were taken. No irrigation was used and no waterlogging was observed during the rainy season. Maize was sown 22 times; 5 plantings were destroyed by cattle or birds. As a result no data are available for the period September–December 1978.

The grain yields clearly followed the rainfall distribution pattern (Fig. 22), suggesting that available moisture is an important production determinant.

Several models were developed to predict maize yields from meteorological data. The simplest one, in which yield is predicted from the total amount of rainfall during the growing season, gave a poor correlation (r^2 = 0.53). The relation was improved when only the rainfall of the period from 15 days before to 25 days after silking was considered (r^2 = 0.69).

In an attempt to predict yields more accurately a simple moisture balance model was developed to calculate the number of moisture-stress days. The maximum amount of available soil moisture in the model was set at 35 mm. This

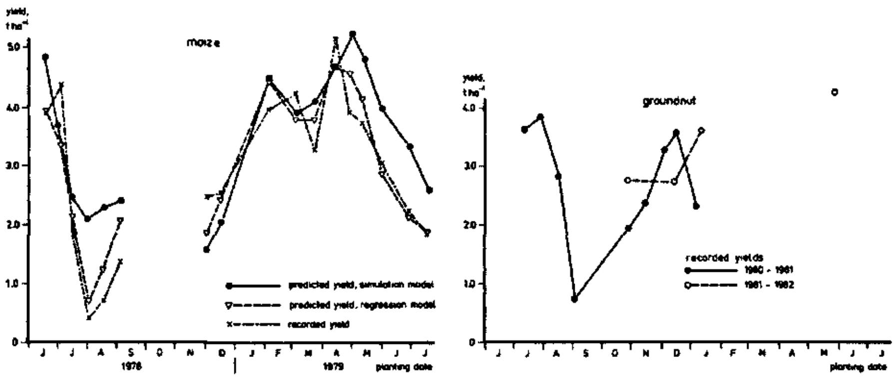


Fig. 22. Actual and predicted yields in the planting-date experiment with maize and actual yields in the planting-date experiment with groundnut (pods).

figure is based on a rooting depth of 30 cm, and a volume fraction of available soil moisture of about 0.12.

The amount of daily available moisture was calculated as available soil moisture at the start of the day plus effective rainfall minus evapotranspiration. If the daily rainfall exceeded 10 mm, only a fraction of 0.8 was considered effective because of runoff losses. If rainfall was less than 10 mm then effective rainfall was assumed to equal daily rainfall.

Evapotranspiration was set at 4 mm per day. Evapotranspiration was assumed to be a linear function of available soil moisture if the latter dropped below the critical value for a stress day.

The model was calibrated for the first 13 plantings of the planting- date experiment. Using different soil moisture values for a stress day and varying the length of the sensitive period around silking, the best relation (r^2 = 0.85) between the actual yields and the number of non-stress days was found for a critical value of soil moisture of 10 mm during the period from 15 days before to 30 days after silking.

In a later stage, actual evapotranspiration was included in the model. Actual evapotranspiration was taken to be a fraction of the open-pan evaporation, E_0, as calculated from the number of sunshine hours, according to the equation

$E_0 = 2.59 + 4.58\ n/N$ (Lenselink & Van der Weert, 1973)

where E_0 = daily open-pan evaporation in mm, and
n/N = daily relative sunshine duration for the period 07.00–17.00 h.

This model was calibrated for 16 plantings. The best relation ($r^2 = 0.87$) between yield and number of non-stress days was found for an evapotranspiration–pan-evaporation ratio of 0.8, a soil moisture value of 12 mm as the criterion for a stress day, and a drought-sensitive period from 17 days before until 32 days after silking, i.e. from 36 to 85 days after planting. The actual yields and the predicted yields are presented in Fig. 22. It shows that the long rainy season is the best growing season for maize, and that the crop must be planted before 1 May. See also Sections 6.1.1, 6.6.2, and 7.1.1.

The following regression equation was found between actual yields and calculated number of stress days:

$$Y = 4700 - 91X,$$

where Y = grain yield in kg ha^{-1}, and
X = number of stress days.

This relation is shown in Fig. 23, in which sunshine in the period from 36 to 105 days after planting is also taken into account. Yields tended to increase

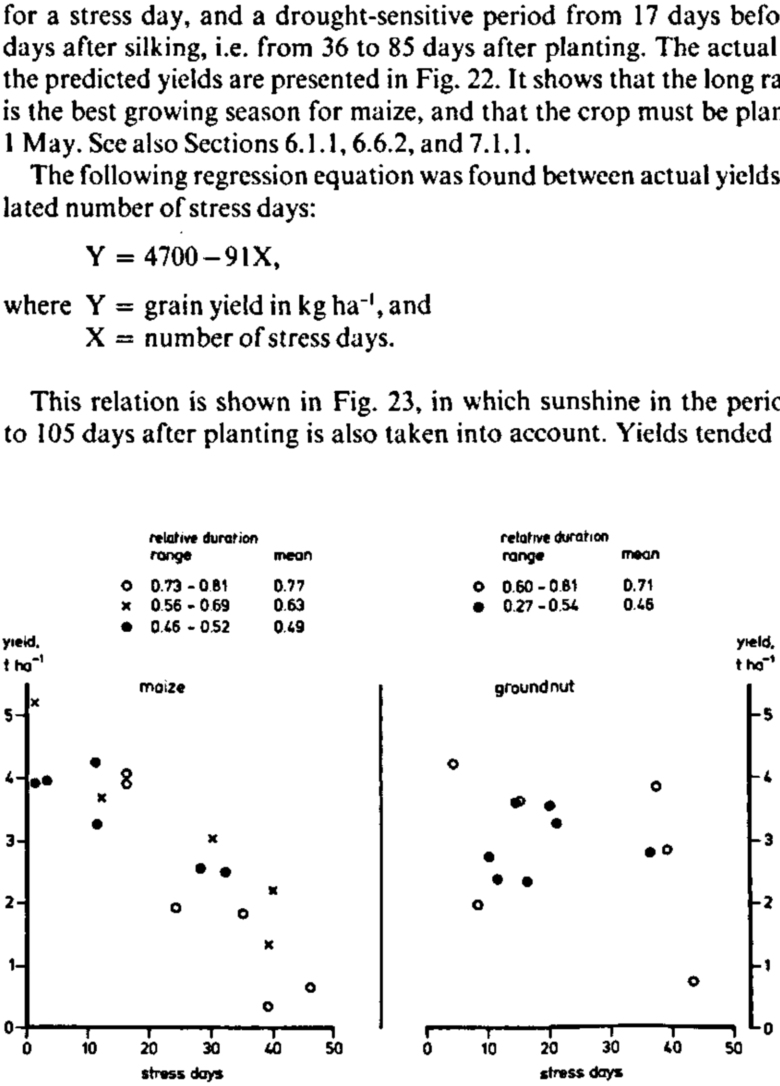


Fig. 23. Relationships between yields, number of stress days and average relative duration of sunshine. Maize: stress days 36-85 days after planting, sunshine 36-105 days after planting. Groundnut: stress days 15-74 days after planting, sunshine 15-70 days after planting.

with duration of sunshine if the number of stress days was less than 20 and to decrease if this number was more than 20.

A similar planting-date experiment as with maize, was carried out with groundnut (cv. Matjan) in the period 1980–1982 (Fig. 22). Planting late in the long rainy season led to yield reduction. The September planting failed because severe drought coincided with the period of flowering. The short rainy season gave highest yields for the December–January plantings but their harvesting was affected by the first rains of the long rainy season; planting earlier in the short rainy season gave lower yields. The highest yield was obtained for the May 1982 planting which was well supplied with moisture until shortly before harvesting.

So far it has not been possible to find a simple explanation for the variation in yield as observed in this experiment. Moisture probably plays a role. No correlation was found between yield and total amount of rainfall during the growing period. Only the September yield can be explained by drought. The number of stress days was calculated for the period between 15 and 64 days after planting, using the same model as used for maize. Fig. 23 shows that this number was hardly related to groundnut yield. Introducing the average daily duration of sunshine for the period from 15 to 70 days after planting did not improve the picture. One of the reasons for the weak relationship is that groundnut is more drought resistant than any other annual crop except cassava. Following a period of prolonged drought the production may be reduced but the crop does not die and is still able to give a reasonable yield.

6.2 Water requirements

In Section 6.1 it was shown that in spite of the humid climate moisture stress can strongly affect yields. Therefore the water requirements of a number of crops were studied in more detail. This was done in lysimeter experiments and in field trials with supplementary irrigation.

6.2.1 Lysimeter studies

The only lysimeter available in Suriname was present at the Centre for Agricultural Research (CELOS) in the coastal area. This lysimeter measuring 1.80 x 1.60 x 1.30 m, was filled with a 1.10 m deep loamy sand on sandy-clay-loam profile from Coebiti, on top of a 20 cm layer of coarse sand. Both lysimeter and surrounding area (160 m^2) were planted with the crop to be studied.

Four crops were grown: maize from March to June 1978, soybean from November 1978 to February 1979, cowpea from March to May 1979 and cassava from June 1979 to October 1980. Weeding, fertilizing and crop protection measures followed standard practices.

During the experiments data were collected daily on evapotranspiration and

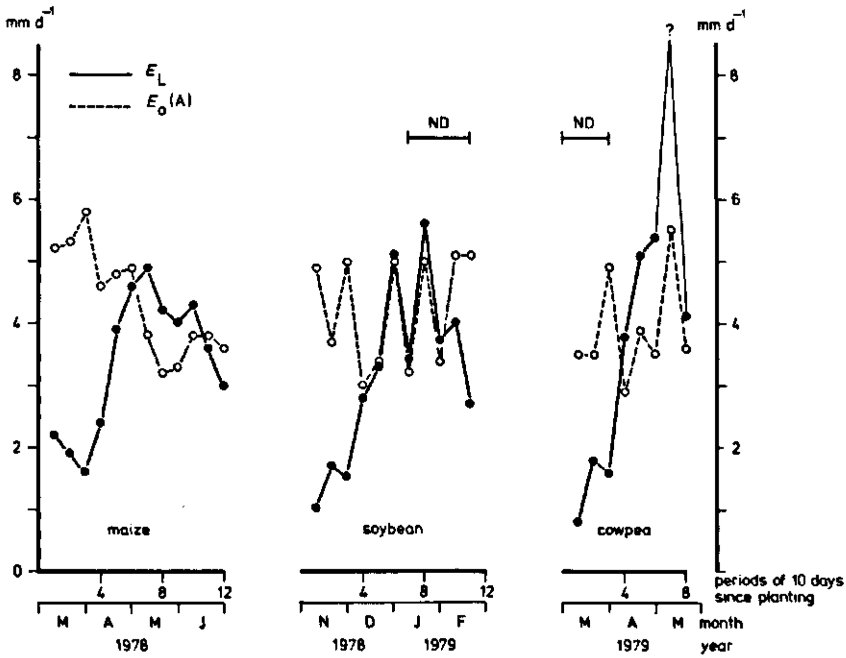


Fig. 24. Course of Class-A pan evaporation (E_0(A)) and evapotranspiration of the lysimeter (E_L) for three annual crops. In the periods indicated by ND there was no percolation from the lysimeter. Data calculated per 10-day intervals.

drainage of the lysimeter, on rainfall, on evaporation of a nearby Class-A pan, and on possible irrigation (Appendix 3). Once a week samples of leachate were taken and analysed for pH, electrical conductivity, and concentrations of N, P, Ca, Mg and K.

In general, a similar pattern in evapotranspiration was found for the three annual crops maize, soybean and cowpea (Fig. 24). Evapotranspiration increased during the first month to a level equal to or higher than that of the Class-A pan evaporation, and it declined during the last 10-day period before harvest. In the period in between, when the crops had their full leaf mass, evapotranspiration followed the variations of the Class-A pan evaporation, indicating that it was regulated by weather conditions rather than by soil moisture availability or by the transpiration capacity of the crop. An exceptionally high evapotranspiration rate was found for cowpea during the first 10-day period of May 1979. No explanation can be provided. In that and the preceding period the ratio E_L/E_0(A) was 1.6, whereas in the others it was maximally 1.3 for maize and cowpea and 1.1 for soybean (Appendix 3).

There were no periods of severe moisture stress, but in January and February 1979 evapotranspiration exceeded precipitation (soybean). Percolation then stopped and the soil started to dry out. Tensiometers placed in the soil at depths

Table 16. Hydrological data (mm per month) from the cassava lysimeter experiment.

Month	Precipitation	Irrigation	Percolation	E_L[a])	$E_0(A)$[b])	$E_L/E_0(A)$
July 1979	303	0	243	29	127	0.2
Aug.	152	0	61	122	150	0.8
Sept.	108	43	0	149	167	0.9
Oct.	28	18	0	100	150	0.7
Nov.	151	86	134	73	127	0.6
Dec.	227	0	151	77	87	0.9
Jan. 1980	41	15	0	73	127	0.6
Febr.	12	60	0	62	155	0.4
March	218	0	72	108	124	0.9
April	190	0	67	104	112	0.9
May	323	0	219	109	96	1.1
June	410	0	293	107	99	1.1
July	394	0	265	(125)[c]	125	1.0
Aug.	63	0	5	(119)	140	0.8
Sept.	104	0	0	(120)	159	0.8
Oct.	200	0	34	(92)	154	0.6

[a]) E_L = evapotranspiration of the lysimeter.
[b]) $E_0(A)$ = Class-A pan evaporation.
[c]) Values in parentheses are not completely reliable.

of 30, 60 and 90 cm showed that the strongest dessication occurred at 90 cm, followed by 60 and 30 cm. This indicates that the soybean had an active root system throughout the profile, but especially in the deep subsoil. Nevertheless, moisture availability was not optimum during this period, which might explain why for soybean $E_L/E_0(A)$ was never more than 1.1.

The data on the cassava experiment are presented in Table 16. The growing period of 16 months can be divided into the following seven stages.

1 The month of establishment, July 1979, was wet. Canopy cover was not complete, evapotranspiration was low and percolation high.
2 During August and September the young plants grew vigorously, canopy cover was nearly 100 per cent, and evapotranspiration (E_L) was high, reaching 90 per cent of pan evaporation ($E_0(A)$). In September the highest E_L of the growing period was measured and irrigation was necessary (43 mm).
3 October. As the weather was very dry, it was decided to study the plants' reaction to drought. No water was given between 2 October and 1 November, and evapotranspiration decreased from nearly 6 mm/day during the first ten days to slightly over 1 mm/day. Soil moisture tension increased from a few kPa to over 8.5 kPa (85 mbars) (maximum measurable with tensiometers). The whole soil profile (0-110 cm) dried out to a moisture volume fraction of around 0.1 (near wilting point). The cassava plants reacted by wilting and shedding nearly all their leaves.
4 In November, after watering and fertilizing, plants slowly started to recover.

The number of leaves per plant increased from 18 to 58, and E_L/E_0(A) increased from 0.21 between 20 and 31 October to 0.88 in December.

5 January and February 1980 were dry and E_L/E_0(A) values dropped. The number of leaves per plant decreased from 58 to 35. Apparently, either recovery from the October drought was not complete or the plants had gone into a kind of rest even though there was enough moisture in the soil (tensiometer values remained below 2 kPa (20 mbar)) thanks to the irrigation.

6 From March to July the weather was wet and there was much percolation. The number of leaves per plant increased from 35 to 134 and E_L/E_0(A) reached values above 1.

7 In the period from August to harvest on 21 October, it gradually became drier and hotter (high E_0(A) values). E_L/E_0(A) values dropped, as did the number of leaves per plant (84 at harvest). (The E_L value for October was low, because there was no crop in the last ten days of the month.) Tensiometer values at 30 cm depth increased to 7 kPa (70 mbar) and decreased later in September, but those at 60 and 90 cm depth did not increase during this dry period.

From Table 16 and Appendix 3 it follows that maximum evapotranspiration could reach values of around 5 mm per day provided the canopy was closed, weather was sunny and moisture stress absent.

In the field, with roots concentrated in the upper 25 cm and a volume fraction of approximately 0.1 for available soil moisture, this soil moisture would be exhausted after five days of sunny weather. Since there will always be some roots that go deeper than 25 cm and the evapotranspiration decreases when the amount of available moisture decreases, it will take slightly longer to exhaust the soil moisture. In practice, wilting symptoms appeared in fully grown maize after one week without rain.

The results of the lysimeter studies show that for crops with a short growing cycle, such as maize, soybean and cowpea, 4-5 mm of water should be available per day from the second month onwards, for certain periods (one month for cowpea and two months for maize and soybean). For cassava 3-4 mm per day throughout its growth cycle might suffice. Although cassava can withstand dry periods, it takes a long time for the crop to recover completely from severe moisture stress.

The data on the weekly analyses of the leachate are summarized in Table 17. Losses of calcium, magnesium, sodium and potassium were high. In the field they might be even higher, because there the rooting depth is about 25 cm, whereas in the lysimeter rooting depth was at least 90 cm. Estimates of nutrient losses in the field are discussed in Sections 6.4 and 6.5.

No nitrogen was found in the leachate. Since the lysimeter subsoil was usually waterlogged and hence anaerobic conditions prevailed, nitrogen must have been lost by denitrification. This process probably contributed to the high pH of the leachate.

Phosphorus was found only in the period November 1979–August 1980. Re-

Table 17. Lysimeter studies. Chemical properties of leachate, and nutrient losses under different crops during different percolation periods.

	March-June 1978 (122 days)	Nov. 1978-Jan. 1979 (71 days)	Nov. 1979-Aug. 1980 (230 days)
	maize	soybean	cassava
pH	7.9-8.5	6.4-8.0	n.d.[a])
Electric conductivity, mS cm^{-1}	0.2-0.6	n.d.	n.d.
P, mmol dm^{-3}	0	0	0.003-0.18
K, mmol dm^{-3}	0.03-0.10	0.08	0.05-0.23
Na, mmol dm^{-3}	n.d.	0.65-0.97	0.04-1.55
Ca, mmol dm^{-3}	0.85-1.96	1.75-2.35	0.57-1.73
Mg, mmol dm^{-3}	n.d.	0.21-0.40	0.23-1.02
Losses per period, kg ha^{-1}			
P	0	0	17
K	11	8	78
Na	n.d.	43	156
Ca	259	177	471
Mg	n.d.	17	144
Losses per day, kg ha^{-1}			
P	0	0	0.07
K	0.09	0.11	0.34
Na	n.d.	0.61	0.68
Ca	2.12	2.49	2.05
Mg	n.d.	0.24	0.63

[a]) n.d. = no data available.

Table 18. Fertilizer nutrient rates (kg ha^{-1}) at the medium fertilizer level[a]) of the irrigation trial. Coebiti.

Cropping cycle and crops	N		P	K	Mg	FTE[b])
	maize	soybean				
1 m, sb[c])	120	20	50	50	71	50
2 m, sb	120	20	50	50	11	0
3 m, sb	140	20	50	80	96	0
4 m, sb	154	0	33	100	105	50
5 m, s	120[d])	-	68[d])	100[d])	15[d])	0
6 sb, g	-	0	25	40	9	0
7 m	150	-	70[e])	100[e])	79[e])	0

[a]) At the low level the rates were half these rates and at the high level they were 1.5 times as high. During the first cycle high rates were double the medium rates. For soybean and groundnut the nitrogen rates were the same at all levels.

[b]) FTE = fritted trace elements, see Section 6.5.7.

[c]) m = maize, sb = soybean, s = sorghum, g = groundnut.

[d]) Sorghum received 100, 65, 80 and 12 kg ha^{-1}, respectively.

[e]) These rates of P, K, and Mg were applied irrespective of the N rates (75, 150 and 225 kg ha^{-1}).

sidual fertilizer phosphorus probably caused the phosphorus concentration in soil and in leachate to increase gradually until the concentration in the leachate was above the detection limit. The higher K and Mg losses per draining day in this period might also have resulted from residual fertilizers.

6.2.2 *Supplementary irrigation*

Between 1979 and 1983 an irrigation trial was conducted at Coebiti to determine the effects of supplementary irrigation and fertilizer rates on yields, and to develop a cropping calendar based on supplementary irrigation. Three fertilizer levels were used – low, medium and high – except for N on soybean, which received only starter nitrogen. Soybean and groundnut seeds were inoculated with specific *Rhizobium*. The fertilizer rates are presented in Table 18. Planting dates were

Table 19. *Calculated moisture deficit and stress days, and details of the different cycles in the trial on supplementary irrigation. Coebiti.*

Cycle	Crop	Planting date	Rel. sunshine[a])	Rainfall[b]) mm	Irrigation mm	Moisture deficit		Stress days
						+ irr. mm	– irr. mm	– irr.
1	maize	79.10.17	0.53	458	160	17	43	10
	soybean	79.10.16	0.54	446	160	1	21	10
2	maize	80.02.20	0.43	813	13[c])	0	0	4
	soybean	80.03.06	0.45	857	0	0	0	0
3	maize	80.08.07	0.77	374	250	24	196	42
	soybean	80.08.14	0.77	352	250	24	196	34
4	maize	81.01.08	0.48	568	146	16	90	24
	soybean	81.01.08	0.47	521	146	16	90	24
5	maize	81.10.27	0.48	404	14[c])	0	0	n.d.[e])
	sorghum	81.10.27	0.48	330	14[c])	0	0	n.d.
6	soybean	82.06.30	0.72	510	t.p.[d])		135	35
	groundnut	82.06.30	0.72	484	t.p.		139	35
7	maize	82.11.11	0.38	416	72	8	37	n.d.

[a]) Relative duration of sunshine during weeks 6-15 for maize and sorghum and weeks 5-14 for soybean and groundnut. For explanation of relative duration of sunshine, see Appendix 8.
[b]) Rainfall during 15, 13, 14 and 13 weeks after planting for maize, sorghum, soybean and groundnut, respectively.
[c]) At the start of the cycle all fields received extra irrigation water: 18 mm in Cycle 2 (maize) and 9 mm in Cycle 5.
[d]) t.p. = technical problems; irrigation was not possible.
[e]) n.d. = no data available.

chosen such that moisture regimes on the rainfed plots differed from one cycle to the other (Table 19). Weekly rainfall, irrigation and pan evaporation are shown in Appendix 4. Yields are given in Table 20.

Generally, irrigation was carried out once a week if during the past seven days evapotranspiration, estimated by multiplying pan evaporation by crop factor, had exceeded rainfall. The crop factor is the ratio of the water use by the crops at optimum moisture supply to the potential evapotranspiration. Its value was derived from the lysimeter studies described above. The amount of water applied equalled the difference between evapotranspiration and rainfall. During the first cycle, an additional 15 mm was applied per irrigation turn to account for moisture losses. As this proved unnecessary it was omitted in the subsequent cycles.

In some cases, all fields received irrigation water at the start of the cycle to enhance germination and save the crop (Cycles 2 and 5). Sometimes soybean had to be resown because of poor emergence caused by drought (Cycles 2 and 3). In Cycles 1 and 7 fields were irrigated before ploughing to enable proper soil tillage.

Tensiometers were placed at depths of 30 and 60 cm. They indicated soil drying in the rainfed plots during the second half of January 1980 (Cycle 1), September and October 1980 (Cycle 3), March 1981 (Cycle 4), September 1982 (Cycle 6) and February 1983 (Cycle 7). In general, subsoils dried out more under soybean than under maize, indicating that soybean roots were more active at greater depths than maize roots and hence soybean was less susceptible to drought than maize. In Cycle 6 it was shown that groundnut could withstand drought even better than soybean (Table 20). Sorghum was grown only in Cycle 5, when rainfall was sufficient, so no data were obtained on its susceptibility to moisture stress.

The effects of irrigation were most evident in Cycles 1, 3, 4, and 7 because these growth periods included parts of the long or the short dry season (Table 19). As fertilizer rates and drought varied from cycle to cycle the yield data in the tables are difficult to compare. Therefore, yields were interpolated for a standard fertilizer application rate (120 kg N and about 50 kg P, 70 kg K and 55 kg Mg ha^{-1} for maize). For soybean the standard application was about 12 kg N, 52 kg P, 75 kg K and 62 kg Mg ha^{-1}. The corresponding yields, presented in Table 20 under the heading 'standard', are compared with moisture conditions during growth (in Figs. 25 and 26). The moisture conditions were characterized according to three methods.

a Total rainfall plus irrigation until maturity, i.e. for maize, sorghum, soybean and groundnut, respectively 15, 13, 14 and 13 weeks after planting.

b Moisture deficit during the critical period, i.e. 5-15 weeks after planting for maize, and 4-14 weeks for soybean. It was calculated over 1-week intervals as the difference between rainfall and pan evaporation. If this difference was negative, it was added to the amount of readily available soil moisture (23 mm per profile at field capacity), and if this sum was negative the sum was taken as moisture deficit (see Appendix 4).

Table 20. Yields (t ha^{-1}) of irrigated (A) and non-irrigated (B) crops in relation to the fertilizer levels. Coebiti.

Cycle	Fertilizer level[a])	Maize			Soybean		
		A	B	A-B	A	B	A-B
1	1	1.80	1.77	0.03	1.83	2.04	−0.21
	2	3.02	2.72	0.30	2.13	1.89	0.24
	3	3.43	2.75	0.68	2.01	2.11	−0.10
	S[b])	3.02	2.72	0.30	2.08	2.02	0.06
2	1	3.78	3.03	0.75	1.81	1.47	0.34
	2	4.02	3.57	0.45	1.79	1.64	0.15
	3	3.53	4.03	−0.50	1.79	1.81	−0.02
	S	3.78	3.57	0.21	1.79	1.82	−0.02
3	1	3.38	0.01	3.37	2.49	0.90	1.59
	2	3.95	0.02	3.93	2.70	0.75	1.95
	3	4.08	0.10	3.98	3.03	0.90	2.13
	S	3.80	0.05	3.75	2.68	0.76	1.92
4	1	2.99	2.17	0.82	2.76	0.67	2.09
	2	3.38	1.99	1.39	2.66	0.90	1.76
	3	3.71	2.08	1.63	3.00	1.03	1.97
	S	3.20	2.10	0.90	2.72	0.79	1.93
					Sorghum		
5	1	4.04	3.92	0.12	3.84	3.86	−0.02
	2	4.40	4.32	0.08	4.28	4.11	0.17
	3	4.48	4.24	0.24	4.44	4.25	0.19
	S	4.40	4.32	0.08	4.35	4.17	0.18
		Groundnut			Soybean		
6[c])	1		1.99			0.70	
	2		1.97			0.65	
	3		2.08			0.71	
	S		2.13			0.70	
7		Maize					
	1	3.31	2.42	0.89			
	2	2.77	2.02	0.75			
	3	2.90	2.07	0.83			
	S	3.00	2.20	0.80			

[a]) See Table 8.
[b]) S = standard fertilizer level. For explanation see text.
[c]) Due to technical problems irrigation was not possible during this cycle.

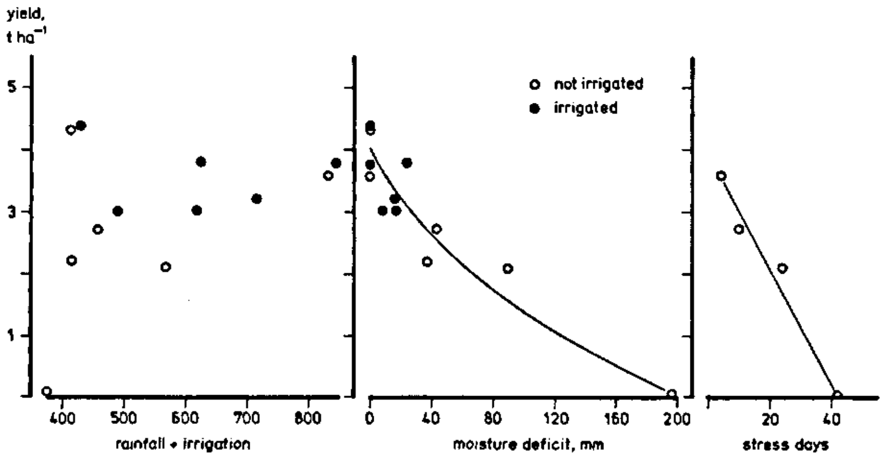


Fig. 25. Maize yields at standard fertilizer level, in relation to rainfall plus irrigation (0-15 weeks), moisture deficit (6-15 weeks) and moisture-stress days (5-12 weeks after planting).

c Moisture-stress days (only for non-irrigated fields) during the interval between 36 and 85 days after planting, calculated as explained in Section 6.1.3.

Fig. 25 shows that there was hardly any relation between maize yield and rainfall plus irrigation. Moisture deficit and stress days were clearly related to yield: roughly one mm moisture deficit corresponded to a yield loss of 20 kg and one stress day to a loss of 95 kg ha^{-1}, approximately the same value as found in the planting-date trial (Section 6.1.3).

Soybean yields were somewhat better related to total rainfall plus irrigation and somewhat less to moisture deficit and stress days than maize yields (Fig. 26). This is probably because soybean can utilize moisture from greater depths than maize, as discussed above. For the calculation of moisture deficit and stress days only the topsoil (0-30 cm) is taken into account, a procedure that is tailored more to maize than to soybean. For soybean, yield losses per mm moisture deficit and per stress day were 12.5 and 47.5 kg ha^{-1}, respectively. Under severe drought (Cycles 3 and 4), soybean yields did not decline as sharply as maize yields.

Fig. 27 shows yield increases as related to irrigation. In Cycle 1 irrigation was 105 mm too high, because in each of the seven irrigation turns 15 mm extra water was applied. Therefore in Fig. 27 the points representing this cycle were shifted from 160 mm irrigation to 55 mm irrigation (lines a and b). Roughly speaking, 10 mm irrigation increased maize yields by 75 kg ha^{-1} and soybean yields by 100 kg ha^{-1}, but because of the rather irregular pattern these figures have an indicative value only.

In Cycle 3 maize yields were very strongly boosted by irrigation (Table 20). This might partly be explained by the very sunny weather: about 7.7 sunshine

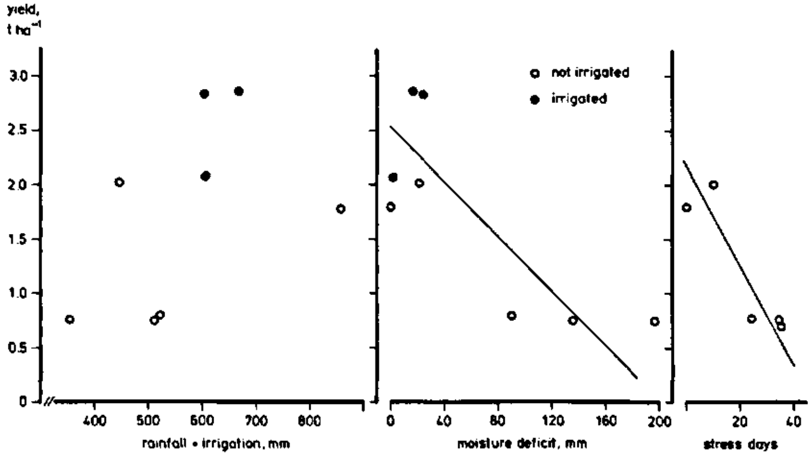


Fig. 26. Soybean yields at standard fertilizer level, in relation to rainfall plus irrigation (0-14 weeks), moisture deficit (5-14 weeks) and moisture-stress days (5-12 weeks after planting).

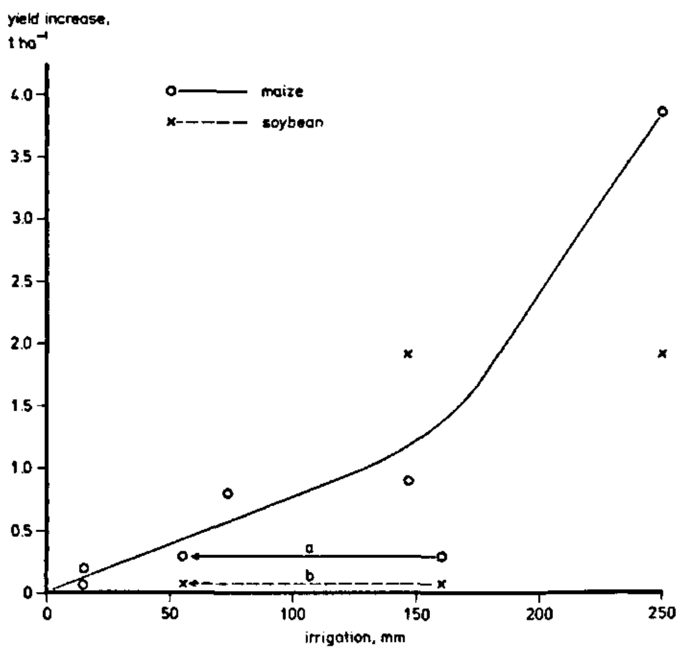


Fig. 27. Increases in yields of maize and soybean by irrigation. For explanation of lines a and b, see text.

hours between 07.00 and 17.00 h during the period between 5 and 15 weeks after planting. In the other cycles the corresponding number of sunshine hours was 4.6 on average.

September and October are the most productive months in terms of the sunshine available for crop production (Section 6.1.1). Moreover, being the long dry season these months offer the best conditions for harvesting. To profit from these favourable circumstances, crops should be irrigated. A serious difficulty is that this requires planting in June or July, when the soil is often too wet for tillage (Section 8.2.2). However, a good cover crop may help to improve workability.

The irrigation trials do not provide information on yield improvement by irrigation prior to soil preparation or immediately after planting, because both irrigated and rainfed plots had received such irrigation. However, it is unquestionable that in Cycles 1, 2, 5, and 7 there would have been no crop at all if no supplementary irrigation had been applied at planting.

Several factors plead in favour for planting in the dry seasons. Rains mostly start abruptly and fields often have to be prepared when the soil is too wet. Loss of soil structure and poor emergence result. The young crop provides little soil cover and the uptake of water and nutrients is still very low, so that erosion and nutrient leaching readily occur. For the short rainy season the end of the growing period is often too dry. To avoid this, in other words to extend the growing period, planting should be in November, about one month before the rains are reliably sufficient for crop growth. Harvesting will then be in the short dry season.

The effects of moisture stress on the crop's response to fertilizer application are discussed in Section 6.6.

6.3 Physical soil conditions and tillage

6.3.1 Physical soil conditions

The Zanderij soils are low in organic matter and have a mineral fraction that largely consists of low activity kaolinite and quartz sand. Except for organic matter, and the varying, but generally small amounts of iron, there are hardly any structure-forming agents that bond soil particles together. This general lack of structure-forming agents results in soils with a low structural stability. Forces from large rain drops and improper soil tillage can easily destroy the topsoil structure, resulting in a reduced infiltration rate, a decrease in macroporosity, increased resistance to root penetration, and surface runoff with erosion.

In this connection, soil texture is important. A certain amount of clay is preferred because clay increases the water-holding capacity. Generally the loamy soils have a higher carbon content than the sandy soils. On the other hand, a higher clay content often results in a lower infiltration rate, slower drainage, more erosion and nearly always in a reduced workability for tillage. Consequently the soil is too wet after rain and too hard when dry.

As shown in Section 5.2.1 mechanized clearing often considerably increased the bulk density of the subsoil. Maximum densities usually occurred between 30 and 50 cm, i.e. below the influence of normal ploughing. However, it needs to be emphasized that poor root development beyond the plough layer was not necessarily caused by a compact subsoil. The chemical condition of the subsoil, characterized by a low pH, a high Al content and the near absence of nutrients, also hindered the root development of most crops. Whatever the reason, most roots remain in the plough layer, so that not more than about 35 mm moisture is available (Section 6.1.3).

The physical problems of the topsoil can be solved with an adequate primary tillage system. Subsoiling might alleviate the physical constraints in the deeper layers. Both practices were studied in the project.

6.3.2 Primary tillage

An extensive account on the tillage experiments has already been given by Goense (1987). Only the main features will be discussed below.

The standard tillage practices consisted of 25 cm deep disc ploughing followed by harrowing; they were adopted from the traditional tillage practices used in temperate Europe. From the start of the research on the Zanderij soils (Section 2.3) it was questioned, however, whether these practices would be appropriate for these soils and conditions. Four tillage experiments were carried out. They will be referred to as the long-term tillage, the mulch tillage, the no-tillage frequency and the Kabo tillage experiments.

The *long-term tillage* experiment (1974-1982) was started to establish the relation between crop yield and the depth of tillage. The tillage treatments were:

1 Ploughing to a depth of 25 cm, followed by harrowing;
2 Rotavating to a depth of 15 cm;
3 Rotavating to a depth of 7 cm. In 1978 this treatment was changed into direct planting; it is denoted by 'no tillage'.

Until 1978 only tillage, planting and cultivation were mechanized. Thereafter all operations were mechanized and pre-emergence herbicides were used for weed control.

The results of 22 cropping cycles with five different crops (Table 21) show that ploughing gave the highest yields and shallow (7 cm) rotavating or no tillage gave the lowest yields. The differences seemed to increase with time, especially for maize. With groundnut there was virtually no difference in yields between rotavating to 15 cm and ploughing. The effects of tillage practices on the root distribution of maize are shown in Fig. 28. On the non-tilled plots the number of roots was about half that on the ploughed plots, and most roots were confined to the top 10 cm. There was little difference in total number of roots between ploughing and rotavating but rotavating caused a concentration of the roots in the top 20 cm.

Table 21. Effects of different forms of soil tillage on yields of different crops. Long-term tillage experiment, Coebiti.

Cycle	Planting date	Yields, t ha^{-1}			Rel. yield (PL = 100)	
		PL[a])	RO	NT	RO	NT
Maize						
2	April 74	2.98	2.73	2.41	92	81
6	Sept. 75	2.90	2.54	2.44	87	84
10	March 77	2.42	2.21	2.15	91	89
16	April 79	2.80	1.64	1.76	59	63
19	April 80	2.24	1.63	1.20	73	54
21	April 81	2.37	1.72	1.65	73	69
	average	2.62	2.08	1.92	79	73
Sorghum						
4	Dec. 74	3.03	2.73	2.51	90	82
8	July 76	0.28	0.27	0.26		
12	Dec. 77	1.40	1.30	1.38	93	99
14	Aug. 78	0.45	0.41	0.33		
18	Nov. 79	2.65	2.02	1.57	76	59
22	Dec. 81	2.71	2.20	2.26	81	83
	average	2.45	2.07	1.93	84	79
Cowpea						
1	Jan. 74	0.84	0.74	0.60	88	71
9	Dec. 76	0.87	0.74	0.55	84	64
17	Sept. 79	0.77	0.75	0.65	97	84
	average	0.83	0.74	0.60	90	73
Soybean						
5	May 75	1.52	1.47	1.16	97	76
11	April 77	1.43	1.37	1.42	96	99
15	Dec. 78	1.75	1.44	1.27	82	73
20	Nov. 80	2.08	1.97	1.89	94	90
	average	1.70	1.56	1.43	92	85
Groundnut						
3	Aug. 74	1.95	1.90	1.68	98	86
7	Jan. 76	2.25	2.32	2.11	104	94
13	May 78	1.52	1.46	1.36	96	90
	average	1.90	1.90	1.72	99	90

[a]) PL = ploughing; RO = rotavating; NT = no tillage.

Though yield and root development were strongly correlated with the depth of tillage, it cannot be concluded whether this is caused by physical or chemical soil differences, as the tillage treatments had some marked effects on both. Soil samples taken in July 1980 showed that the distribution of Ca, Mg and P over the top 30 cm improved with the depth of tillage. With no tillage these nutrients remained confined to the top 10 cm, with 15-cm rotavating to the first 20 cm,

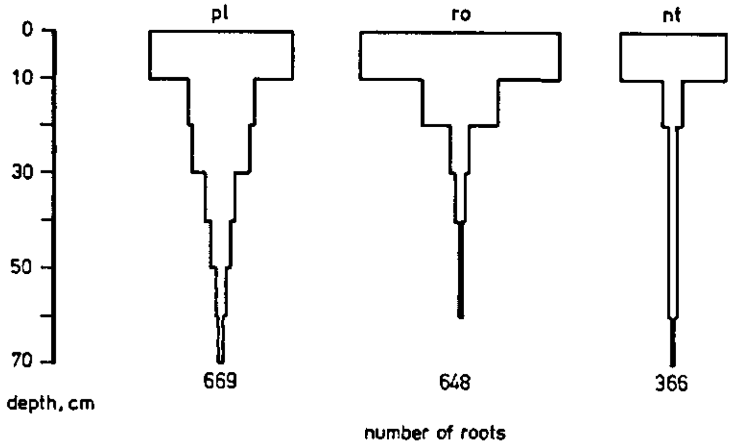


Fig. 28. Relative densities of maize roots in 0.10 x 0.30 m cross-sections for ploughing (pl), rotavating (ro), and no tillage (nt).

whereas with ploughing, high concentrations were found throughout the top 30 cm of the soil profile. Consequently, toxic levels of Al and a low pH appeared higher in the profile as the depth of tillage decreased (Table 22).

Ploughing reduced the penetration resistance of the top 30-35 cm of the soil profile. With rotavating this resistance increased to 2.8-3.5 MPa at a depth of 25 cm, whereas on the non-tilled plots values of 2.5-3.4 MPa were recorded from 15 cm downwards (Fig. 29).

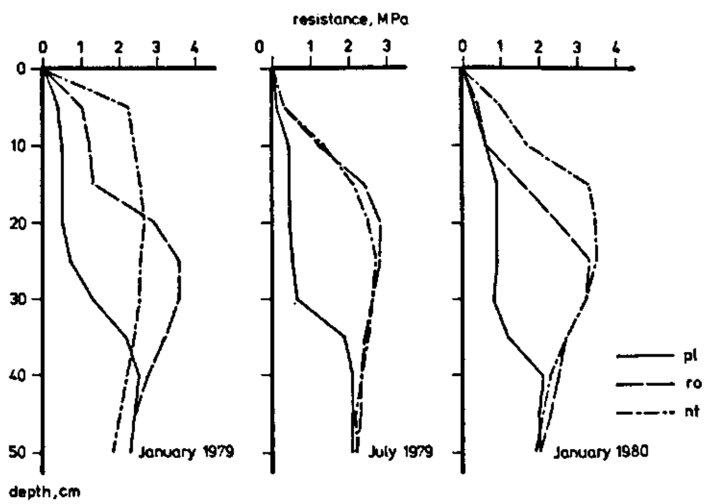


Fig. 29. Penetrometer resistance (MPa) in soils to 50 cm, as affected by ploughing (pl), rotavating (ro), and no tillage (nt).

Table 22. Effects of different tillage systems on chemical soil properties of the 0-20 and 20-40 cm soil layers in July 1978 and July 1980. Long-term tillage experiment, Coebiti.

		0-20 cm		20-40 cm	
	Treatment[a])	July 78	July 80	July 78	July 80
Org. C, g kg^{-1}	PL	12.6	10.9	8.4	8.4
	RO	11.3	10.9	7.5	6.2
	NT	12.3	12.8	7.7	7.6
Org. N, g kg^{-1}	PL	1.0	0.8	0.7	0.6
	RO	1.0	0.8	0.8	0.5
	NT	1.0	0.9	0.7	0.5
P-Bray-I, mg kg^{-1}	PL	27.1	20.3	8.5	13.8
	RO	24.2	32.6	4.2	7.5
	NT	24.1	32.7	4.7	4.1
pH (KCl)	PL	4.4	4.5	4.1	4.3
	RO	4.3	4.6	4.1	4.2
	NT	4.3	4.3	4.0	4.0
Ca[b])	PL	19.4	14.0	9.5	10.2
	RO	15.1	15.0	4.6	5.9
	NT	15.2	19.4	4.7	6.1
Mg	PL	2.1	3.4	1.3	1.8
	RO	1.7	3.3	0.7	3.1
	NT	1.7	3.4	0.7	1.5
K	PL	0.7	0.7	0.6	0.6
	RO	0.6	0.9	0.4	0.7
	NT	0.8	0.6	1.1	0.8
Na	PL	0.5	0.5	0.2	0.3
	RO	0.2	0.7	0.2	0.4
	NT	0.7	0.4	0.4	0.4
Al	PL	3.2	2.8	6.5	4.6
	RO	3.8	1.1	8.7	6.3
	NT	4.7	2.2	10.4	7.0
ECEC	PL	25.9	18.4	18.1	18.1
	RO	21.4	20.2	14.6	14.7
	NT	23.1	23.6	13.4	12.7
Al/ECEC	PL	0.12	0.14	0.36	0.25
	RO	0.18	0.05	0.60	0.39
	NT	0.20	0.13	0.78	0.39

[a]) PL = ploughing; RO = rotavating; NT = no tillage.
[b]) Exchangeable cations and ECEC: ionic equivalents, mmol kg^{-1}.

Whatever the nature of the causes, chemical or physical, the results clearly show that deep tillage is essential and that continuous no tillage or shallow tillage results in lower yields than ploughing.

In the *mulch tillage* experiment minimum tillage and conventional tillage (ploughing and harrowing), both with or without additional mulch, were compared (1978-1980). In the minimum-tillage treatment a narrow strip was tilled. Fertilizer was incorporated into the tilled soil. Crop residues from outside sources were used as extra mulch at a rate of 10 tonnes dry matter per hectare.

In the first three cropping cycles minimum tillage outyielded conventional tillage (Table 23), but in Cycles 4 and 5 the differences were reversed. After Cycle 5 the entire field was ploughed, but this could not eradicate the accumulated effects of the no-tillage treatment. Mulching had a positive effect, except in Cycle 6 when excessive weed growth had an overriding, detrimental effect on crop yields. The weeds had probably been brought along in the form of seeds with the mulch.

Table 23. Effects of tillage and mulch on yields (t ha^{-1}) of six consecutive crop cycles. Coebiti.

Cycle	Crop	Planting date	No tillage		Ploughing	
			no mulch	with mulch	no mulch	with mulch
1	maize	June 78	2.40	2.98	2.14	2.49
2	cowpea	Nov. 78	1.16	1.38	0.98	1.18
3	mungbean	March 79	1.04	1.04	0.78	1.00
4	maize	June 79	0.88	1.10	1.44	1.74
5	soybean	Dec. 79	0.58	0.62	0.66	0.82
6[a])	maize	April 80	2.12	2.10	2.38	2.30

[a]) Before the sixth crop was planted, all plots were ploughed.

Table 24. Effects of tillage on pore space and on some chemical soil characteristics as measured after five cycles of the mulch tillage experiment. Data were averaged over the mulch treatments. Coebiti.

	No tillage		Ploughing	
Sampling depth, cm	0-20	20-40	0-20	20-40
Pore space, volume fraction	0.425[a])	0.388[b])	0.442[a])	0.396[b])
P-Bray-I, mg kg^{-1}	13.9	2.6	10.7	3.2
pH (H_2O)	5.2	4.6	5.1	4.8
Ca[c])	1.52	0.58	1.49	0.84
Mg	0.29	0.10	0.22	0.14
Al	0.37	0.89	0.44	0.74

[a]) Average of 2-7 and 10-15 cm samples.
[b]) Sampling depth was 20-25 cm.
[c]) Exchangeable cations: ionic equivalents, mmol kg^{-1}.

Physical and chemical soil properties were affected in a similar way as in the long-term tillage experiment. Pore space was higher with ploughing than with minimum tillage, and ploughing improved the chemical characteristics of the 20-40 cm soil layer (Table 24).

No-tillage frequency. Although continuous no tillage leads to yield reduction, it also has some advantages: the field operating system is simpler; labour, equipment and direct energy costs are lower; the workability range for planting is wider; less time is required to establish a planted area. To study whether it would be possible to profit from both tillage systems, a field experiment was set up with intermittent no tillage, permanent ploughing and permanent no tillage (Table 25).

In general, yields with ploughing were higher than with no tillage, irrespective of the previous treatment. The yields on the intermittent no tillage plots were 14 per cent above the yields of permanent no tillage. In the second cycle, field work was interrupted by heavy rains, and therefore the ploughed fields were planted five days later. The resulting poor conditions remained, so that in this cycle non-tilled plots yielded better than ploughed ones.

The *Kabo tillage* experiment comprised the treatments with chisel ploughing (25 cm) and disc harrowing (15 cm), with disc ploughing (25 cm) and no tillage as reference. A series of four cropping cycles was carried out. For detailed information on growth conditions, see Goense (1987). The data in Table 26 again show that disc ploughing resulted in the highest yields. Chisel ploughing followed closely. No tillage yielded least in this case too. An exception was Cycle 2, when because of drought the germination of soybean was poor on the tilled plots, especially in the wheel tracks, whereas there were no such problems on the no-tillage plots.

In conclusion, ploughing resulted in higher yields than no tillage. However, it is not necessary to plough for each cropping season. Direct planting with

Table 25. Effects of no-tillage frequency on yields (t ha^{-1}) of six consecutive crops. Coebiti.

Cycle	Crop	Planting date	Treatments[a]) and yields			
1	sorghum	Dec. 80	PL 3.4	NT 2.8	NT 2.8	NT 2.9
2	maize	May 81	PL 2.0	PL 1.6	NT 2.7	NT 2.1
3	soybean	Dec. 81	PL 2.0	NT 1.4	PL 2.0	NT 1.4
4	maize	May 82	PL 3.2	NT 2.4	PL 3.4	NT 1.9
5	sorghum	Jan. 83	PL 3.0	PL 2.9	NT 2.3	NT 1.9
6	maize	May 83	PL 3.3	NT 3.5	NT 3.3	NT 2.9
Mean relative yield, per cent			100	85	100	76

[a]) PL = ploughing; NT = no tillage.

Table 26. Effects of different tillage systems on yields (t ha^{-1}) of four crop cycles in the Kabo tillage experiment.

Cycle	Crop	Planting date	Tillage system[a])			
			NT	DH	CP	DP
1	maize	April 81	2.01	2.03	2.38	2.40
2	soybean	Nov. 81	2.32	2.00	1.99	2.04
3	maize	Dec. 82	2.88	3.11	3.89	3.89
4	sorghum	July 83	0.89	1.04	1.34	1.53
Mean relative yield, per cent			83	83	96	100

[a]) NT = no tillage; DH = disc harrowing; CP = chisel ploughing; DP = disc ploughing.

or without shallow tillage might be recommended, especially when the conditions are marginal for mechanized field operations, as is often the case for planting in the long rainy season. Under the conditions prevailing in the Zanderij area the approach towards the tillage operations in a mechanized cropping system should be flexible.

6.3.3 Subsoiling

If a compact soil layer occurs below ploughing depth, subsoiling might be of advantage. It is a form of deep tillage whereby the compact layer is loosened and at the same time slightly lifted, so that a slight mixing of subsoil and plough layer takes place. Subsoiling should be done when the soil is hard and dry so that the subsoil breaks up in lumps, thus increasing pore space. Subsoiling experiments were carried out at Coebiti and Kabo, with a subsoiler that had a working depth of about 50 cm.

Table 27. Effects of subsoiling on maize, soybean and groundnut yields (t ha^{-1}). Coebiti.

Cycle	Planting date	Crop	With subsoiling (A)	Without subsoiling (B)	Difference (A-B)
1	Jan. 79	maize	3.05	3.38	−0.33
		soybean	0.87	0.89	−0.03
		groundnut	1.11	1.08	+0.03
2	Dec. 79	maize	0.27	0.18	+0.09
		soybean	0.92	0.76	+0.16
		groundnut	1.37	0.99	+0.38
3	April 80	maize	2.66	2.74	−0.08
		soybean	2.17	1.98	+0.19
		groundnut	1.72	1.55	+0.17

Coebiti. Maize, soybean and groundnut were used as test crops during three cycles (Table 27). The first subsoiling was done in September 1978 four months before planting, with runs 130 cm apart and 50 cm deep. The second subsoiling was in November 1979, with runs 75 cm apart to give a better opening up of the soil. The soil was moist during the treatment, but January and February 1980 were very dry with only 76 mm of rain. Maize suffered particularly from drought: frequent wilting, stunted plants and only a few small ears. Soybean and groundnut were able to withstand the drought much better (see also Section 6.2.2).

Between the second and the third cycles no subsoiling took place. The third cycle coincided with the main rainy season. Groundnut suffered from fungal diseases despite frequent fungicide applications.

In the first cycle, the effect of subsoiling on maize was not statistically significant, and on soybean and groundnut it was virtually zero. Subsoiling could not have had much effect here, as the treatment took place four months before planting and was not intensive (subsoiler runs 130 cm apart). In the second cycle, yield differences were relatively large and statistically significant in favour of the subsoiled plots. This could be because of the drought (deep rooting being more important during dry periods than during wet ones). In the third cycle subsoiling had no significant positive effects.

The effect of subsoiling was short-lived. Virtually no traces were found in a profile pit dug seven months after subsoiling.

Kabo. The field chosen for a subsoiling experiment at Kabo was in a very poor condition because clearing, windrowing and preparatory tillage had taken place under conditions that were too wet. Part of the topsoil was lost and permeability had decreased; during the rainy seasons water stagnation and erosion occurred and in dry periods the soil was hard. Four cycles were grown with maize and soybean as test crops. Subsoiler runs were always 75 cm apart. Subsoiling for the first cycle was carried out at the end of October 1980. It was not repeated for the second cycle. The following runs were in October 1981 and 1982. In 1981 the soil was moist because of much unexpected rainfall around mid-October. The stirring action of the subsoiling was still acceptable but not ideal. In 1982 the soil was very dry and working depth was between 35 and 40 cm. In this fourth cycle supplementary irrigation was included as an additional variable. The field was irrigated between 26 January and 20 February 1983; a total amount of 91 mm of water was applied.

Table 28 shows that soybean did not respond to subsoiling. Maize on subsoiled plots yielded 5 to 8 per cent more than on the control plots, but the differences were never statistically significant. In the fourth cycle only the irrigated maize responded positively to subsoiling. The effect of the supplementary irrigation was larger than that of subsoiling. Table 29 shows that subsoiling resulted in a lower penetrometer resistance, especially between 15 and 35 cm.

To sum up: subsoiling had weak positive effects and some negative effects

Table 28. Effects of subsoiling on maize and soybean yields (t ha^{-1}). Kabo.

Cycle	Planting date	Crop	With subsoiling (A)	Without subsoiling (B)	Difference (A-B)
1	Nov. 80	maize	4.12	3.90	+0.22
		soybean	2.29	2.39	−0.10
2	April. 81	maize	4.27	3.95	+0.32
		soybean	2.65	2.65	0.00
3	Nov. 81	maize	4.70	4.48	+0.22
		soybean	failure		
4	Dec. 82	maize	4.85	4.89	−0.04
	+ suppl. irr.		5.73	5.38	+0.35
		soybean	not planted		

Table 29. Penetrometer resistance (MPa) in the soil profile as influenced by subsoiling. Averages of 8 to 16 observations. About one month after subsoiling. Kabo.

Depth, cm	With subsoiling (A)	Without subsoiling (B)	Difference (B-A)
10	1.14	1.97	0.83
20	1.38	2.91	1.53
30	2.05	3.51	1.46
40	2.15	2.94	0.79
50	1.88	2.45	0.57
60	1.86	2.29	0.43
70	1.95	2.33	0.38

on crop growth. The positive effects originated from loosening the subsoil and from some mixing of topsoil with subsoil which resulted in deeper rooting and better drainage. A negative effect was that poor, acid subsoil that had scarcely any organic matter and a very poor structural stability was mixed with the topsoil. In the long run these negative effects of an impoverished topsoil might disappear.

The effect of subsoiling on subsoil bulk density was short-lived, as the soil readily compacted again because of its low structural stability. The effect of mixing subsoil with topsoil lasted longer, resulting in a subsoil less hostile to roots. However, it is unlikely that the costs of subsoiling are offset by the returns from higher yields.

6.4 Soil acidity and liming

6.4.1 Indices of soil acidity and their interrelationships

Soil acidity is usually denoted by pH measured in a suspension of soil in water or in a solution of a salt. In this project water and a 1 M-KCl solution were used with a soil–liquid mass ratio of 1:2.5.

The pH measured in a salt solution (pH(KCl)) is lower than the pH measured in water (pH(H_2O)), as long as the pH is above the zero point of charge (Sanchez, 1976). For the topsoils of our trial fields there was an almost linear relationship between pH(H_2O) and pH(KCl), the latter being about 0.8 lower than the former (Fig. 30). The pH values were 0.4-2.0 higher than those in forest soils (Tables 5 and 10). This increase had been brought about by liming and in some cases by ashes from burnt original vegetation.

Generally, annual crops do not perform well on acid soils. Usually the poor growth is not caused by H^+ ions, but by a number of factors related to low pH (Sanchez & Cochrane, 1980). An acid soil is often synonymous with a chemi-

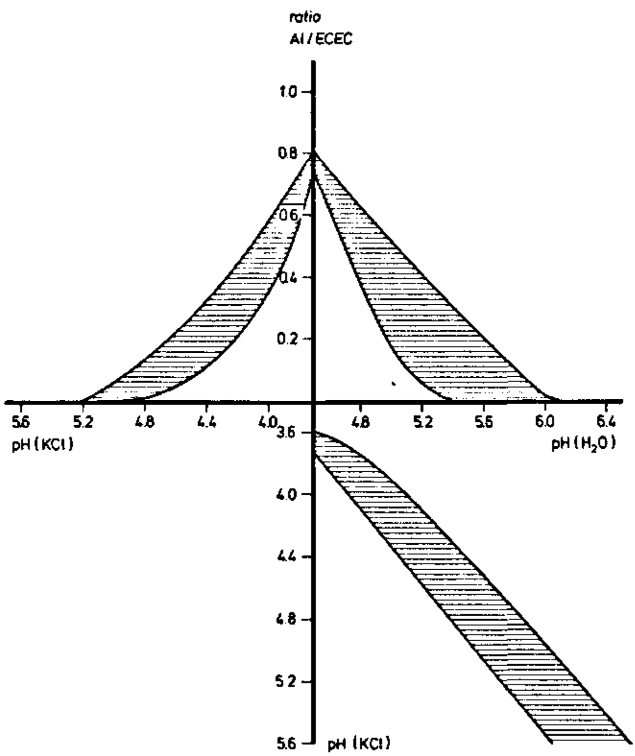


Fig. 30. Relationships between substance ratio of ionic equivalents of Al to effective CEC, pH(H_2O) and pH(KCl) (0-20 cm). Curves based on data from approximately 200 samples.

cally poor soil, having deficiencies in all primary and secondary nutrients. The concentrations of Al and Mn ionic species are high in the soil solution and these ions directly harm plant roots. Because it is rather cumbersome to sample a soil solution and because the Al activity in the solution depends upon the Al saturation of ECEC, the ratio of Al to ECEC is often used as a criterion in recommendations for liming tropical soils (Cochrane et al., 1980; Kamprath, 1970). This ratio is also related to pH.

Fig. 30 shows that for the Kabo and Coebiti soils the relationship between Al/ECEC and pH(H_2O) was more diffuse than that between Al/ECEC and pH(KCl). This was probably caused by fluctuations in pH(H_2O), which in contrast to pH(KCl) is affected by the concentration of the salts in the soil solution. Fertilizer application, uptake of nutrients by crops and leaching changed the salt concentrations, and therefore the values for pH(H_2O) were influenced by time of sampling.

6.4.2 Soil reaction and yields

In a number of field trials pH(KCl) was determined in topsoils (0-20 cm) of individual plots. The data were compared with yields (Fig. 31). As yield levels varied considerably among the trials, the relationship between yield and pH(KCl) showed up more clearly for relative yields than for absolute yields. Only the yields of plots that had received the same experimental treatments – apart from liming – were compared. Because of lack of data it was not possible to draw similar graphs for pH(H_2O) and Al/ECEC.

Yields of maize, soybean and groundnut proved to be suppressed by a low as well as by a relatively high pH. The negative effect of too low a pH was almost certainly related to Al toxicity, but it was not clear why yields decreased at high pH. Deficiencies in micronutrients such as Zn, Cu or Mn might be a

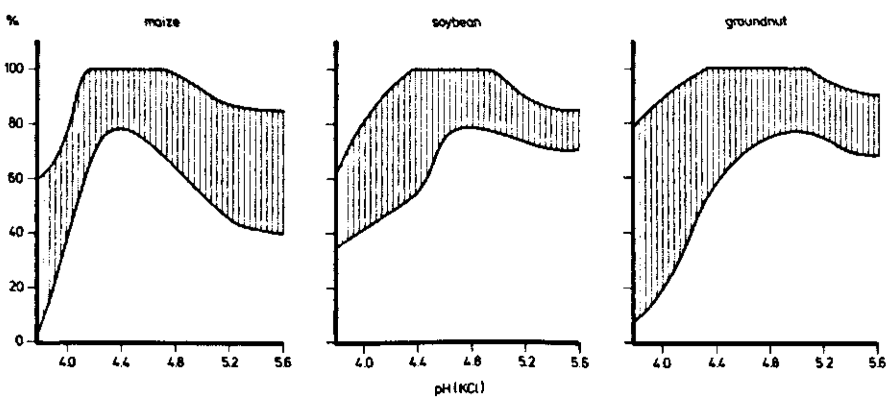


Fig. 31. Ranges of relative yields of maize, soybean and groundnut, as related to pH(KCl) (0-20 cm).

Table 30. Ranges of optimum values of three soil acidity indices for maize, soybean and groundnut.

	Maize	Soybean	Groundnut
pH (KCl)	4.2-4.6	4.5-5.0	4.5-5.2
pH (H_2O)	5.0-5.6	5.2-6.0	5.2-6.2
Al/ECEC	<0.40	<0.25	<0.25

reason, though experiments on micronutrients were not conclusive (Section 6.5.7).

The optimum ranges for pH(KCl) were converted via the graphs of Fig. 30 into ranges of optimum pH(H_2O) and Al/ECEC (Table 30). The ranges were almost the same for soybean and groundnut, whereas maize required a somewhat lower pH or, in other words, could withstand a somewhat higher Al saturation. The critical values of 0.25-0.40 for Al/ECEC were in accordance with what is generally found.

At the end of the project, application of gypsum (300 kg ha^{-1}) was included in the liming trials. Its effect depended on soil pH: pod yields of groundnut increased from about 1.0 to 2.7 t ha^{-1} if pH(KCl) was 4.0-4.1, and from 3.2 to 3.5 t ha^{-1} if pH(KCl) was between 4.4 and 4.8. The effect of gypsum was probably the result of an increased availability of calcium.

6.4.3 Lime requirements

To be able to increase pH or to reduce Al saturation to their optimum levels information is needed on the amount of lime that is required per unit pH or per unit Al. This was studied in a trial at Coebiti on a soil with the following characteristics: organic C 11-12 g kg^{-1}; CEC, ECEC and exchangeable Ca, Mg and Al 40, 15.7, 1.1, 0.5 and 13.5 mmol kg^{-1} (ionic equivalents), respectively. Agricultural lime containing about 90% $CaCO_3$ was applied at rates of 2 and 5 t ha^{-1} and incorporated in the upper 15 cm of the soil. Changes in pH and related properties were followed during 22 months after applying lime.

Exchangeable Ca was linearly related to liming (Fig. 32C). At 30 days after liming its increase per tonne of agricultural lime amounted to 9 mmol kg^{-1}. This points to a complete recovery, because 9 mmol kg^{-1} ionic equivalents of Ca correspond with 360 x 10^6 mg Ca or 900 kg ha^{-1} pure $CaCO_3$ or 1000 kg ha^{-1} agricultural lime (assuming that lime was equally distributed over the top 20 cm and that bulk density, so soon after rotavating, was 1.0 Mg m^{-3}).

Lime requirement, as deduced from the approximately linear relationship between pH(KCl) and lime application (Fig. 32A), was about 300 kg lime; this is about 135 kg pure $CaCO_3$ per 0.1 pH (KCl) per 10 cm topsoil, i.e. per 10^6 kg of soil.

Cochrane et al. (1980) proposed the following equation to calculate the required quantity of lime:

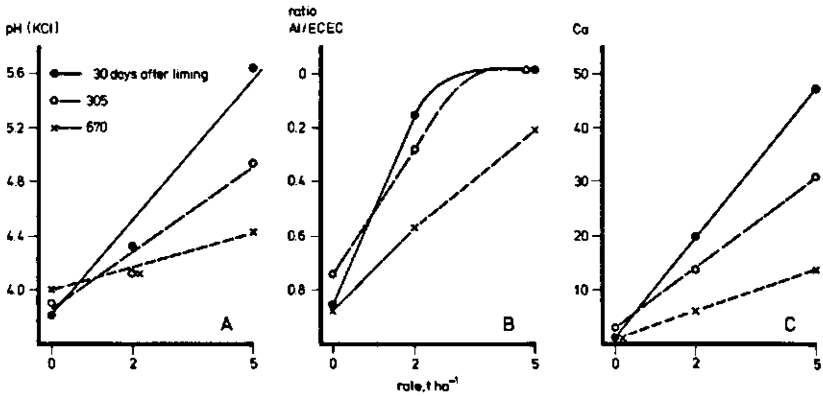


Fig. 32. Effects of rate of lime on pH(KCl), ratio Al/ECEC and ionic equivalents of exchangeable Ca (mmol kg^{-1}) at 30, 305 and 670 days after liming for a Coebiti sandy loam (0-20 cm).

$$Ca = 1.5\{Al - RAS(Al + Ca + Mg)/100\},$$

where exchangeable Ca, Mg and Al are in mmol kg^{-1} (ionic equivalents) and RAS = required percentage Al saturation.

If the lime requirement estimated this way exceeds the chemical equivalent of exchangeable Al, the factor 1.5 should be replaced by 2.0.

According to Table 30, RAS is 25 for soybean and groundnut. Substituting this value and the abovementioned data gives:

$$Ca = 1.5\{13.5 - 25(13.5 + 1.1 + 0.5)/100\} = 14.5875$$

This value being greater than the chemical equivalent of exchangeable Al, i.e. 13.5, the factor 2.0 should be used, which results in 19.45 mmol kg^{-1} of ionic equivalents of Ca. Per 2 10^6 kg of soil, these values come down to 29 175 and 38 900 mol, respectively, i.e. 1459 and 1945 kg pure $CaCO_3$ or 1621 and 2161 kg agricultural lime. The measured value of 1730 kg (Fig. 32B) was between these two.

According to Fig. 32A 2 tonnes of agricultural lime were required to reach the optimum pH(KCl) of 4.5; this corresponds closely with the abovementioned rates of 1621 and 2161 kg ha^{-1}.

The reason that the quantity of lime needed exceeds the quantity of Al neutralized, is that ECEC increases upon liming, because of the dissociation of -COOH and -OH groups of soil organic matter and hydroxides (Kamprath, 1970). The extra negative charge is usually counterbalanced by Ca^{2+} ions.

At Coebiti, ECEC increased gradually up to pH(KCl) 4.8 but increased sharply at higher pH (Fig. 33). This sharp increase is to be considered partly as an analytical artefact, caused by Ca being dissolved from lime during the

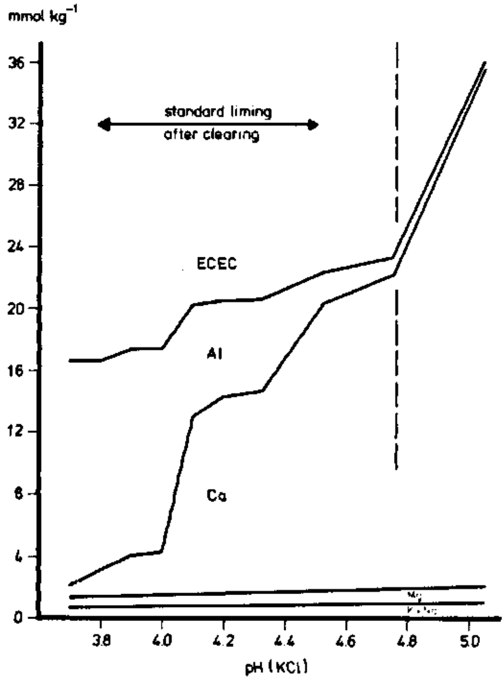


Fig. 33. Summation of ionic equivalents of exchangeable cations and ECEC in relation to pH(KCl) for a Coebiti sandy loam (0-20 cm).

extraction of the soil samples.

Over the pH(KCl) interval 3.8 – 4.5, which is the most important range in practice, exchangeable Al (ionic equivalents) decreased from 13.5 to 2.0, whereas exchangeable Ca increased from 1.8 to 19.0 mmol kg^{-1}. So, the relation Ca/Al was 17.2/11.5 = 1.5, the same value as Kamprath (1970) found in comparable situations.

Fig. 32 also shows that with time pH and exchangeable Ca dropped markedly and Al/ECEC increased strongly. The recovery of lime was estimated on the basis of exchangeable Ca in the 0-20 and 20-40 cm soil layers and assuming bulk densities of 1.0 and 1.4 Mg m^{-3}, respectively. Fig. 34 shows that one year after application about half the amount of lime applied had already leached from the top 20 cm of soil. After 670 days (22 months), the fractions left in 0-20 and 0-40 cm layers were 0.3 and 0.55, which amounted to monthly losses of 5.5 and 3 per cent, respectively.

Thus, in practice, the lime requirement of Zanderij soils should be reckoned at 2 tonnes of lime per ha after clearing and subsequently one tonne of lime per ha per year.

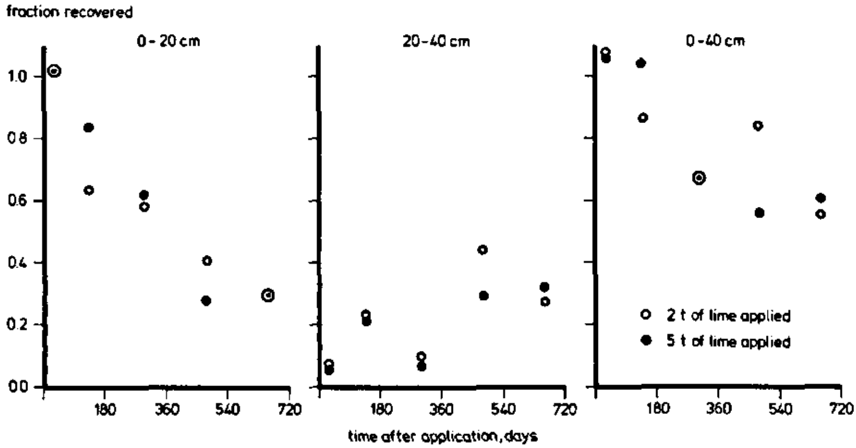


Fig. 34. Estimates of fractions of applied lime recovered in 0-20 and 20-40 cm soil layers of a Coebiti sandy loam in the course of time.

6.4.4 Liming materials

The rapid losses of finely ground agricultural lime called for other liming materials that dissolved more slowly. The two available were Curaçao phosphate with mass fractions of 0.7 for $CaCO_3$ and 0.3 for tertiary calcium phosphates, and shell grit, a coastal deposit of broken shells with a shell mass fraction of about 0.7.

In a trial conducted in 1983, one tonne of each of these materials was as effective as approximately 0.3 tonne of dolocal (a fine dolomitic lime) in increasing pH and exchangeable Ca at 120 days after application. So, the initial application rates of Curaçao phosphate and shell grit should be three times that of dolocal, but it still remains to be been seen whether their effects will last longer.

6.5 Availability of nutrients and fertilizer use

6.5.1 General discussion on nutrient–crop relationships

6.5.1.1 Introduction to the three-quadrant method

Optimum fertilizer rates are usually arrived at after much empirical research in field, greenhouse and laboratory. This work could be greatly reduced if the following were known

1 the crop's utilization of absorbed nutrients;
2 the crop's recovery of applied fertilizer nutrients;
3 the supply of nutrients from the soil (inherent soil fertility).

The relationships between inherent soil fertility, fertilizer application and yield will be discussed with the help of the so-called three-quadrant procedure, introduced by De Wit (1953) and applied by several other authors. The relationship between fertilizer application and yield (Quadrant II in Fig. 35) is divided into the relationships between fertilizer application and nutrient uptake (Quadrant IV) and between nutrient uptake and yield (Quadrant I).

Nutrient uptake is almost always linearly related to fertilizer application over a wide range of application rates. The slope of the straight line, representing the fraction of the applied nutrients recovered, and the intercept, being the amount of nutrients absorbed from the soil itself, vary with soil, climate and nutrient.

The relationship between nutrient uptake and yield also is linear, at least at low uptake rates, i.e. as long as that particular nutrient is the most important yield-limiting factor, or in other words as long as other growth factors are not yield limiting. For N and P, Van Keulen (1977) and Van Keulen & Van Heemst (1982) found that this straight line had the same slope under various conditions. Even all cereals behaved in a similar way: grain yields (moisture content 0.15) increased by 70 kg per kg N absorbed and by 600 kg per kg P absorbed. For potassium the slope varied between 55 and 80 kg per kg K absorbed. The ratio of the yield increase per additional unit of absorbed nutrient is an expression of the efficiency of nutrient utilization by the plant.

The decision to analyse the results of fertilizer trials according to the three-quadrant model was taken after the field work of the project had been terminated. The fertilizer trials had not been designed with that intention and only a limited number of complete chemical crop analyses were available.

Subsections 6.5.1.2-6.5.1.5 present general information on N, P, K, Ca and Mg for the crops maize, sorghum, soybean, groundnut, and cowpea. The subsequent sections discuss the individual nutrients and crops in more details.

6.5.1.2 Uptake–yield relationships

Table 31 shows that there were wide ranges in the values for total uptake of nutrients (exclusive the nutrients in the roots) per tonne of produce. The main factor influencing these values proved to be the harvest index, i.e. the ratio of grain to total dry weight, as indicated for maize in Table 32. The harvest index itself was affected by factors other than nutrient supply, such as moisture stress during ripening, pests, diseases, and inappropriate tillage. This implies that in many cases low yields were not the result of an insufficient uptake of nutrients, but of an ineffective utilization of the absorbed nutrients.

The standard values for nutrient uptake (lower half of Table 31) represent the quantities of nutrients sufficient to produce one tonne of seeds or pods under conditions that were otherwise rather favourable for this project. Per tonne of maize or sorghum the amounts of N, P and K required were respectively 25, 4 and 20 kg ha^{-1}. In other words, per kg of absorbed N, P and K yields increased by 40, 250 and 50 kg ha^{-1}, respectively. This is considerably lower than the 70, 600 and 80 kg increases mentioned by Van Keulen & Van Heemst (1982). It

Table 31. Ranges and standard values for uptake of nutrients (kg) per tonne of grain or pods (groundnut).

Crop	N	P	K	Ca	Mg
Ranges					
maize	18-77	2.2-9.7	8-72	5-14	3.3-10.7
sorghum	23-38	3.5-5.5	15-47	4- 8	2.2- 3.6
groundnut	51-62	2.8-3.5	7-17	12-19	4.0- 6.7
soybean	79-97	6.4-7.8	46-60	n.d.[a])	4.7- 5.4
cowpea	57-62	6.9-8.5	31-42	18-26	5.3- 6.7
Standard values					
maize	25	4	20	10	5
sorghum	25	4	20	5	3
groundnut	60	3	12	16	6
soybean	90	7	50	18[b])	5
cowpea	60	7	32	20	6

[a]) n.d. = no data available.
[b]) Estimated value.

Table 32. Indicative values for the uptake of nutrients (kg) per tonne of maize grain as related to the harvest index.

Harvest index	N	P	K	Ca	Mg
0.2-0.3	40-70	6-9	> 25	5-14	5-11
0.3-0.4	20-40	4-6	10-25	9-10	3- 6
≥0.4	18-20	2-4	10-25	n.d.[a])	n.d.

[a]) n.d. = no data available.

Table 33. Normative good grain or pod (groundnut) yields and corresponding requirements of nutrients (rounded figures).

Crop	Yield $t\ ha^{-1}$	Nutrients, $kg\ ha^{-1}$				
		N	P	K	Ca	Mg
maize	4.5	115	18	90	45	25
sorghum	3.5	90	14	70	20	10
groundnut	4.0	240	12	50	65	25
soybean	2.5	225	18	125	45[a])	15
cowpea	1.25	75	9	40	25	8

[a]) Estimated value.

can therefore be inferred that plants could not make optimum use of the available nutrients; this indicates that other growth conditions must have been rather unfavourable in this project.

Using the standard values of Table 31, nutrient requirements were calculated for normative good yields (Table 33), which were set at about 90 per cent of the frequency distribution (Figs. 54, 56, 57, 58 and 61), i.e. about 10 per cent of the yields obtained were higher than these normative good yields. The most exacting crops for P and K were maize and soybean, and for Ca and Mg maize and groundnut. Soybean and groundnut required twice as much N as maize, but being legumes they demand only a small portion of it from soil and fertilizer.

6.5.1.3 Recovery of fertilizer nutrients

The recovery of fertilizer nutrients was calculated with the equation:

$$\text{recovery} = (U_2 - U_1) / (F_2 - F_1)$$

where F_1, F_2 = lower, higher fertilizer application rate, kg ha^{-1}, and
U_1, U_2 = corresponding amount of nutrients taken up, kg ha^{-1}.

Since yields were very low when no fertilizers were applied, control treatments had been included in only a few trials. As a consequence F_1 in the above equation was mostly more than 0 kg ha^{-1}.

The number of data (Table 34) were limited. For maize a subdivision could be made into applications below and above optimum rate. At below-optimum application rates recovery of P was high compared with literature data, indicating that P fixation was not a problem. The recovery of N and K was normal for a humid climate. The main reason for the low recoveries at above-optimum application rates was problably that crops were unable to utilize the absorbed nutrients (Section 6.5.2.2).

Table 34. Indicative values for the fraction of fertilizer nutrients, recovered by the aboveground plant parts of different crops.

Crop	A.R.[a])	N	P	K	Mg
maize	1	0.30-0.50	0.15-0.25	0.35-0.60	0-0.10
	2	0.03-0.20	0.03-0.06	0.20-0.30[c])	n.d.[b])
sorghum		0.18-0.32[d])	0-0.10[e])	0.20-0.30[d])	n.d.
groundnut		n.d.	n.d.	0.20-0.30	0-0.40
soybean		0-0.40	n.d.	n.d.	n.d.
cowpea		n.d.	0-0.05[e])	n.d.	n.d.
standard values		0.40	0.20	0.50	0.10[c])

[a]) A.R. = application rate; 1 = below, 2 = above optimum rate; see Section 6.5.2.2.
[b]) n.d. = no data available.
[c]) Estimated values.
[d]) Sorghum was sown after kudzu had been ploughed in.
[e]) Trials were conducted on a P-rich soil.

Table 35. Indicatives values for the amounts (kg ha^{-1}) of nutrients supplied by the soil alone to different crops.

Crop	N	P	K	Mg
maize	30-50[c])	3-10[d])	10-25[e])	5-10
sorghum	30[f])	10-12[g])	30[f])	n.d.[a])
groundnut	n.a.[b])	n.d.	13-24	8-16
soybean	n.a.	n.d.	n.d.	n.d.
cowpea	n.a.	5-8[g])	n.d.	n.d.
standard values	35	n.a.[d])	20	7

[a]) n.d. = no data available.
[b]) n.a. = not applicable.
[c]) N uptake depended on soil organic nitrogen content.
[d]) P uptake depended on P content in soil.
[e]) Exchangeable K was less than 0.7 mmol kg^{-1}.
[f]) Sorghum was sown after kudzu had been ploughed in; uptake from kudzu residue was estimated at 50 and 60 kg ha^{-1} for N and K, respectively, and from the soil itself at 30 kg ha^{-1}.
[g]) Trials were conducted on a P-rich soil.

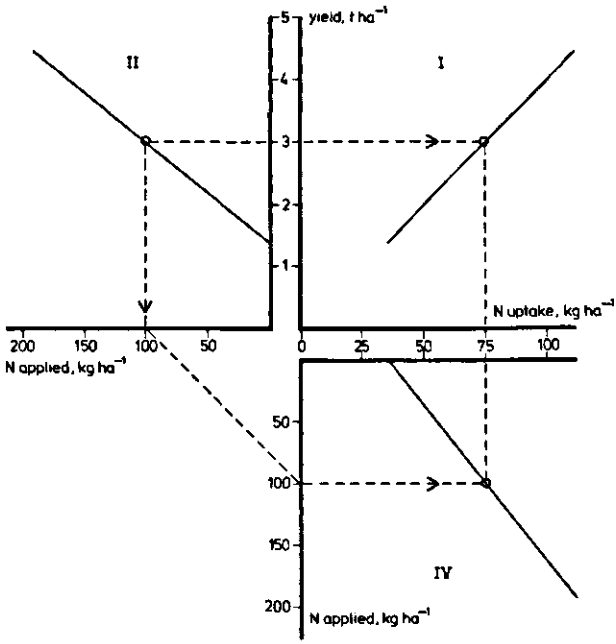


Fig. 35. Three-quadrant diagram for the response of maize to nitrogen according to the standard values presented in Tables 31, 33, 34 and 35. I. Yield against uptake. II. Yield against fertilizer rate. IV. Uptake against fertilizer rate.

6.5.1.4 Nutrient supply by the soil

As mentioned, nutrient uptake was only occasionally measured in crops that had not received the relevant fertilizer. Therefore most data presented in Table 35 could only be obtained indirectly by extrapolating application vs uptake curves (Quadrant IV in Fig. 35). Nutrients other than the one in question were supplied in adequate amounts.

Nevertheless, the data were sufficient to indicate standard values. The values for N were independent of previous fertilizer applications, because this nutrient does not accumulate in the soil. In contrast to N, P continues to accumulate in the soil upon fertilizer application, and therefore P uptake from the soil depends on previous applications (Section 6.5.3). K and Mg have an intermediate position (Sections 6.5.4 and 6.5.5).

A comparison of Tables 33 and 35 shows that the soil's contribution to the nutrient requirements for normative good yields was only modest.

6.5.1.5 Standard three-quadrant diagrams

The standard values presented in Tables 31, 33, 34 and 35 can be used to draw standard three-quadrant diagrams. An example for the maize–nitrogen relationships is given in Fig. 35. The reasoning was as follows.

The N supply by the soil alone is 35 kg ha^{-1}, corresponding with a yield of 35/25 = 1.4 t ha^{-1}. Let the normative good yield of 4.5 t ha^{-1} of maize be the highest yield to be obtained, requiring a nitrogen uptake of 4.5 x 25 = 112.5 kg ha^{-1}; then 112.5 – 35 = 77.5 kg ha^{-1} has to be taken up from fertilizer N. With a recovery of 0.4 this amounts to an N application of 77.5/0.4 = 194 kg ha^{-1}.

From such relationships it can be calculated what yield will be obtained upon fertilizer application. After an N application of e.g. 100 kg ha^{-1}, the uptake of N will be: 35 (from soil) + 0.4 x 100 (from fertilizer) = 75 kg ha^{-1}, and the yield: 75/25 = 3 t ha^{-1} of maize grain.

The graphs of Fig. 35 might be considered as a simplified model of the relationships between soil, fertilizer and crop nitrogen, and yield of maize on Zanderij soils. In practice the situation can considerably differ from this picture, as will be discussed in the next sections.

6.5.2 Nitrogen

6.5.2.1 Type and method of application of nitrogen fertilizers

In the project, nitrogen was normally applied as compound fertilizer (15-15-15) at planting and as urea for later applications. At planting the fertilizer was band-placed a few cm away from the seed. Later applications were side-dressed along the plant row.

For practical reasons, in larger field experiments the first application often was given as a side-dressing shortly after emergence, when plant rows were clearly visible. There was no evidence that this delay had a negative effect on crop development. On the contrary, when leaching losses are high nitrogen

Table 36. Influence of splitting the application of fertilizer nitrogen on maize yields. After Bakema (1981) and Slaats & Ukkerman (1983).

Number of applications	Method of splitting	Time of application[a])	Yield, $t\ ha^{-1}$	
			for N rate, $kg\ ha^{-1}$	
			160	180
1		0	2.08	
2	1/2 + 1/2	0-4	2.73	
	1/3 + 2/3	1-7		4.31
	2/3 + 1/3	1-7		5.95
3	3 × 1/3	0-4-7	3.43	
		1-5-9		4.99
6	6 × 1/6	1-3-5-7-9-11		5.92

[a]) Weeks after planting.

would be more effective if applied above the root system instead of under the seed. The nitrogen needs during the first week are covered by the supply in the seeds, especially when these are large. Banding the fertilizer is nevertheless recommended for the first application when the root systems are still small or before any roots are present. Later the root systems will be large enough to benefit from broadcast fertilizer nitrogen.

Generally, nitrogen fertilizer was applied in three portions for maize and sorghum, i.e. at planting and 4 and 7 weeks after planting. For leguminous crops only a starter application was given.

Trials designed to find out the optimum way of splitting applications showed that when only one application was given at planting the yield was lower than when the application was split into two or three portions. Table 36 shows that splitting into more than two portions was not necessary, provided the first application was relatively high and the second portion was not applied until 7 weeks after planting.

In the earlier days of the project calcium ammonium nitrate was introduced for grain legumes as an alternative for urea, in order to reduce the risk of the *Rhizobium* inoculum being inactivated by acidification. Being very hygroscopic this fertilizer is difficult to handle. In later experiments urea was used without obvious detrimental effects.

In a few experiments the effect of the slow release fertilizer sulphur-coated urea (SCU) was studied. The results were disappointing and its use is therefore not recommended.

6.5.2.2 Maize and sorghum

Yields. Fig. 36 shows the results of ten trials with maize and one with sorghum. Table 37 provides some details on these trials. Unless stated otherwise, N was applied in three equal portions (Section 6.5.2.1).

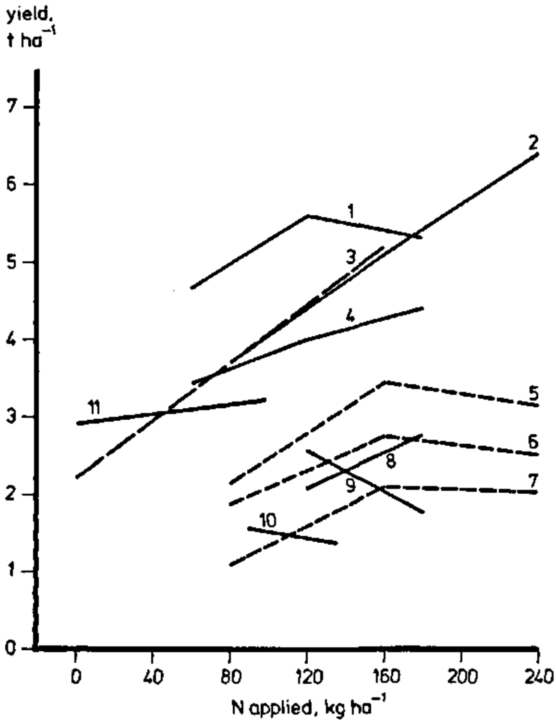


Fig. 36. Response of maize (Curves 1-10) and sorghum (Curve 11) to rate of fertilizer N. Details are given in Table 37 and in text.

Yields and responses to fertilizer N varied strongly, for various reasons. In Trial 8 accidental spraying with paraquat hampered early maize growth. Trials 9 and 10 were planted too late and the crop suffered severely from drought during the long dry season. In Trial 11 kudzu had been ploughed in before sorghum was sown; the contribution of mineralized kudzu N to N uptake was estimated at 50 kg ha^{-1}; moreover the leaf fungi *Colletotrichum graminicola*, *Curvularia* sp. and *Exserohilum turcicum* had heavily infested the crop some weeks before harvest.

In Trials 5, 6 and 7 yields were rather low as a result of waterlogging and runoff after planting. In these trials splitting the N application clearly improved yields and responses to N, up to an N rate of 160 kg ha^{-1}. In Trials 3 and 11 different splitting treatments were also investigated, but because yields did not vary significantly, only the mean yields of these treatments were plotted in Fig. 36.

It is unlikely that varietal differences (Table 37) contributed to the variation in yields, as all cultivars were high producers (Section 7.1). It is also unlikely that the location played a role, because on both farms, Kabo and Coebiti, low

Table 37. Details of the nitrogen trials on maize and sorghum presented in Fig. 36 and Fig. 37.

Number	Location	Growth period	Cultivar
1	Kabo	81.11.19-82.03.30	CMS 04
2	Coebiti	82.05.12-82.09.04	Across 7728
3	Coebiti	82.05.12-82.08.31	Across 7728
4	Coebiti	81.05.11-81.09.02	San Andres
5, 6, 7[a])	Kabo	80.04.15-80.07.31	San Andres
8	Coebiti	80.04.18-80.07.30	San Andres
9	Coebiti	78.06.01-78.09.29	CS 1
10	Coebiti	79.06.21-79.10.08	Cotaxtla
11[b])	Coebiti	81.12.10-82.03.12	Martin

[a]) Fertilizers were split-applied in three, two and one portion, respectively.
[b]) Sorghum was sown after kudzu had been ploughed in.

and high yields were obtained. Furthermore, tillage was the same in all trials (disc ploughing) and pH was always in the optimum range (pH(KCl) 4.2-4.6).

For a closer examination of the cause of yield variation it was necessary to bring recovery of fertilizer N and efficiency of N utilization into the study.

Recovery of fertilizer N and utilization of absorbed N. In Trials 3, 5, 6, 7, 10 and 11, crops were chemically analysed, so that N uptake could be calculated and three-quadrant diagrams could be drawn. Fig. 37 shows that the high yields and strong response in Trial 3 were related primarily to a better N utilization by the crop and not to a larger N uptake from the soil or a higher fertilizer N recovery than in other trials. Utilization efficiency in Trial 3 (Quadrant I) was near the maximum found by Van Keulen & Van Heemst (1982) whereas those of the other trials were far below. As shown in Section 6.5.1.2 a low utilization efficiency was accompanied by a low harvest index. In Trials 3, 11, 5, 6, 7 and 10, harvest indices were approximately 0.43, 0.36, 0.26, 0.24, 0.21 and 0.27, respectively.

The differences in yield between Trials 5, 6 and 7 also reflected differences in recovery (Quadrant IV), created by the splitting methods. Recovery was particularly low in the case of one application (Trial 7); the waterlogging after planting certainly contributed to leaching and denitrification. Where increased application of fertilizer N depressed yield (Trials 10, 5, 6 and 7), recovery was low, but positive, and utilization efficiency was negative. This shows up more clearly in Fig. 38, where the slope of the rate–yield curve, $\Delta Y / \Delta F$, is split into the slopes of the uptake–yield ($\Delta Y / \Delta U$ = efficiency of utilization) and the rate–uptake ($\Delta U / \Delta F$ = recovery) curves. The slopes are related as follows:

$$\Delta Y / \Delta U = \Delta Y / \Delta U \times \Delta U / \Delta F$$

where Y, F and U are yield, fertilizer-N rate and N uptake, respectively, all expressed in kg ha^{-1}.

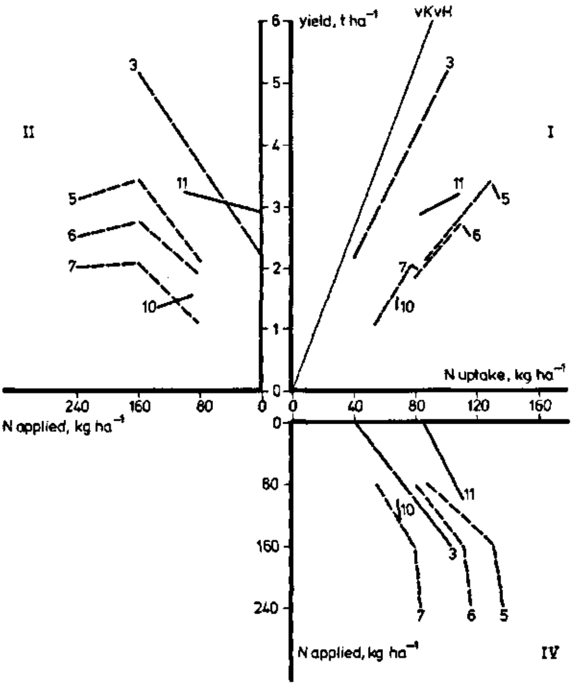


Fig. 37. Three-quadrant diagram for the responses of maize (Curves 3, 5, 6, 7, 10) and sorghum (Curve 11) to nitrogen; vKvH is maximum according to Van Keulen & Van Heemst (1982). Details are given in Table 37 and in text.

Although the number of data were limited it seems justified to conclude (Fig. 38) that as long as maize responded positively to N application, recovery was more than 0.3, and when maize responded negatively, recovery was below 0.1. This suggests that the low recovery at high N application rates resulted from the crop's inability to utilize the extra N absorbed. A low recovery is therefore not the cause but the result of the yield decline.

As can be concluded from Fig. 36, there was neither a critical yield nor a critical application rate above which the response to N application changed from positive to negative. Moisture stress was very probably involved (Boxman et al., 1985b). The relation between N and moisture and its consequences for the recommendations for the application of fertilizer N are discussed in Section 6.6.2.

6.5.2.3 Grain legumes

The grain legumes tested in the project appeared to be capable of acquiring sufficient nitrogen by symbiotic fixation. Adequate nodulation was ensured by applying specific *Rhizobium* inoculum regularly on a routine basis when planting legumes. Commercial inoculum was obtained from Nitragin Co. Inc., Clear-

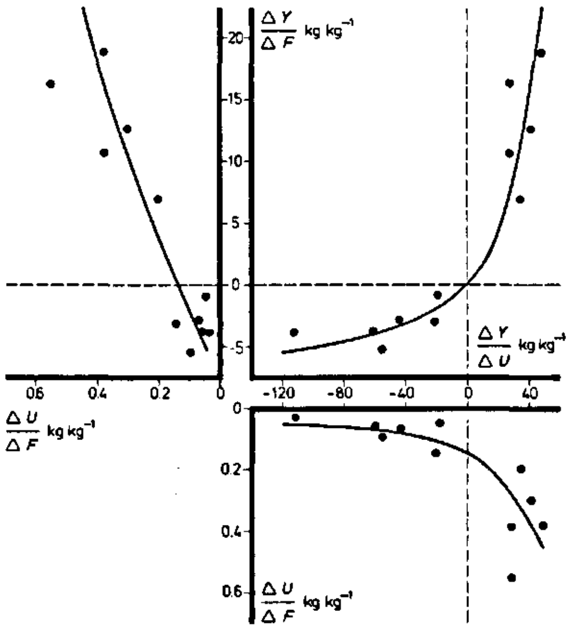


Fig. 38. Three-quadrant diagram for the slopes of the rate–yield ($\Delta Y/\Delta F$), the uptake–yield ($\Delta Y/\Delta U$) and the rate–uptake ($\Delta U/\Delta F$) curves for nitrogen. For explanation see text.

water, Florida, USA. A granular formulation (Soil Implant) was chosen to reduce the risk of bacteria being inactivated by high soil temperatures, dessication and low pH. The rate of application used was 0.6 g (metre row)$^{-1}$ or 12 kg ha^{-1} for crops grown in rows 50 cm apart. The inoculum was always applied in contact with the seed.

There is experimental evidence, although limited, that *Rhizobium* enchances crop performance. In a field experiment with groundnut and cowpea including different rates of starter nitrogen, *Rhizobium* applied at planting increased the number of nodules, total nodule weight, and plant N content of groundnut 27 days after planting. Inoculation significantly (P = 0.05) increased pod yield by 8.5 per cent. Small amounts of nitrogen applied at planting increased the yield of non-inoculated groundnut but had little effect when inoculum had been applied, the increase from inoculation being larger than from fertilizer nitrogen (Table 38). With cowpea the results were erratic, probably because cowpea Rhizobia are generally omnipresent.

Positive effects of *Rhizobium* inoculation on growth of soybean were observed in the field when the granule applicator of the planter failed and parts of rows did not receive inoculum. For weeks after emergence such plants remained small and yellow, and leaf nutrient (especially N) concentrations were lower than in inoculated plants (Table 39).

Table 38. Effect of *Rhizobium* inoculation and fertilizer nitrogen on grain legume yields. Coebiti extension.

Crop	Planting date	Inoculation	Yield, t ha^{-1} for N rate, kg ha^{-1} 0	10	20	40
groundnut[a])	March 79	–	2.11	2.24	2.20	2.32
		+	2.38	2.44	2.35	2.46
	Dec. 81	+	2.97		3.09	3.27
soybean[b])	April 81	+			3.40	3.36
	Dec. 81	+	2.91		2.94	2.96
cowpea[b])	Nov. 78	+			1.18	1.17
mungbean[b])	March 79	+			0.92	1.01

[a]) Pod yields
[b]) Seed yields

Table 39. Effect of inoculation on nutrient mass fractions (g kg^{-1}) of soybean leaves at 61 days after planting. Kabo.

	N	P	K	Ca	Mg
Non-inoculated	26.0	2.1	19.2	13.3	2.7
Inoculated	43.3	2.4	20.9	14.8	3.1

No data are available on the persistence of the *Rhizobium* bacteria in the soil when the host plant is absent. Generally, each grain legume crop was inoculated to avoid possible shortages of nitrogen. Results from nitrogen fertilizer experiments indicated that an N application of 20 to 40 kg ha^{-1} at planting had hardly any effect (Table 38).

6.5.3 Phosphorus

6.5.3.1 Type and method of application of phosphorus fertilizers

In the project the standard P fertilizers were triple superphosphate (TSP, 19% P or 44% P_2O_5) and several compound fertilizers, mainly 15-15-15, 12-10-18 and 13-13-21. The standard methods of application were banding below the seed at planting and side-dressing (of compound fertilizers) later in the season. Usually, all phosphorus was applied at planting.

Trials were conducted to study the effectiveness of Curaphos, a phosphate rock comprising 75% of $CaCO_3$, and 25% of calcium phosphates, and containing 4-5% P. In view of its composition Curaphos could serve both as P source and

Table 40. Maize yields (t ha^{-1}) as influenced by source and method of application of fertilizer P (kg ha^{-1}) on a soil with P-Bray-I of 7.5 mg kg^{-1}. Kabo.

Treatment	Triple superphosphate		Curaphos	Maize yield
	banded	broadcast	broadcast	
1	0	80	0	1.48 b[a])
2	40	40	0	1.91 ab
3	80	0	0	2.15 a
4	0	0	80	0.37 c
5	40	0	40	1.87 ab

[a]) Yields followed by the same letter do not differ significantly (P = 0.05).

as liming material. Like other liming materials, it is broadcast and incorporated into the soil.

Table 40 shows that banding of TSP on a soil low in P-Bray-I gave a better response than broadcasting (Treatments 1 and 3) and that Curaphos was less effective than TSP (Treatments 1 and 4). A P rate of 40 kg ha^{-1} applied as TSP in bands proved sufficient (Treatment 5 vs Treatments 2 and 3) on this soil. The fraction of TSP-P recovered at this application rate is about 0.19, if it is assumed that per tonne of maize 4 kg P is taken up (cf. Table 31) and that Curaphos did not substantially contribute to P uptake (Treatments 4 and 5). This value is within the range indicated in Table 34 and shows that there was no serious P fixation.

The better response to banding compared with broadcasting must be attributed to the immediate availability of P to the seedling roots.

Table 41. Effect of rate of fertilizer P on yields of five consecutive crops following clearing in 1978, and on P-Bray-I (0-20 cm) measured at the start of the growing season, just before the next phosphorus application. P-poor soil at Coebiti extension.

Crop	Yield, t ha^{-1}			P-Bray-I, mg kg^{-1}		
	for fertilizer P, kg ha^{-1}			for fertilizer P, kg ha^{-1}		
	0	30[a])	60	0	30	60
maize[b])	0.00	1.95	2.83	1.0	1.0	1.0
groundnut[b])	0.85	2.03	1.99	1.9	7.6	9.8
sorghum[c])	0.13	0.26	0.44	1.3	3.4	17.3
mungbean[d])	0.06	0.34	0.29	2.0	4.3	9.5
maize[d])	0.00	2.19	2.55	0.8	4.1	6.8

[a]) P applications to groundnut were 25 and 50 kg ha^{-1}.
[b]) These fields had been limed at a rate of agricultural lime of 2 t ha^{-1} in September 1978.
[c]) These fields had been limed at a rate of agricultural lime of 5 t ha^{-1} in September 1978.
[d]) These crops had not received fertilizer P.

6.5.3.2 P-Bray-I and recommendations for fertilizer P

Available soil-P (P-Bray-I) was very low under forest, 2 mg kg^{-1} (Table 5). After clearing P-Bray-I varied between 2 and 8 mg kg^{-1}, depending on the method of clearing (Table 10).

The data in Table 41 refer to a trial conducted after clearing on a field where no vegetation was burnt in situ. The response to fertilizer P was very sharp, and if no P was applied, crops failed completely. The maize grown between April and August 1980, still responded strongly to fertilizer P applied in and before September 1979, showing that there was an important residual effect of fertilizer P. This is reflected also by the P-Bray-I values in Table 41.

After about 20 crops, P-Bray-I is around 30 mg kg^{-1} (see next section). On such soils the response of crops to fertilizer P is erratic, but that of P-Bray-I is still regular (Table 42).

Fig. 39 shows that for low P-Bray-I values the amount of P taken up from the soil increased strongly with rising P-Bray-I; the P uptake was about 10 kg ha^{-1} at P- Bray-I of 8 mg kg^{-1}. The crops would probably have absorbed more P at P- Bray-I values above 8, if other growth factors (pH, N application, moisture conditions) had not been yield-limiting.

Fig. 39 combined with the data from Tables 33 and 34 forms the basis for the P fertilizer recommendation scheme of Table 43. The recommendations are valid for the first crop after the soil has been analysed. For subsequent crops the rates can be lower because of the residual effect of fertilizer P.

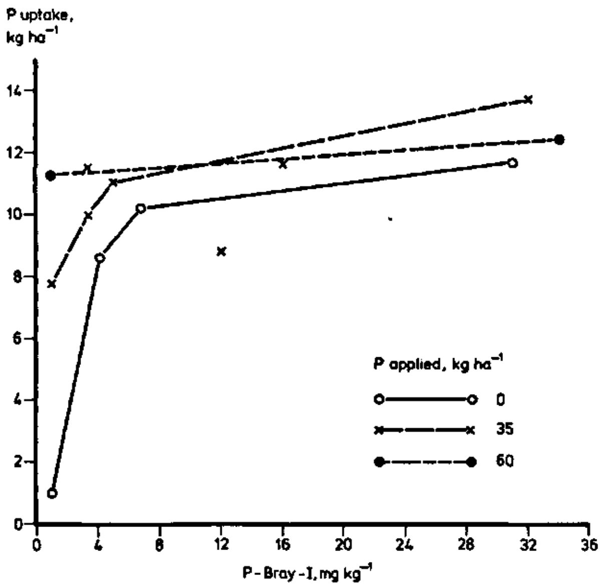


Fig. 39. Relationships between P uptake by maize or sorghum and P-Bray-I (0-20 cm) for three rates of fertilizer P.

Table 42. Effect of rate of fertilizer P on yields of four consecutive crops, and on P-Bray-I (0-20 cm) as measured at the start of the growing season just before the next phosphorus application. P-enriched soil at Coebiti after about 20 crop cycles.

Crop	Yield, t ha^{-1}			P-Bray-I, mg kg^{-1}		
	for fertilizer P, kg ha^{-1}			for fertilizer P, kg ha^{-1}		
	0	30	60	0	30	60
maize	2.48	3.51	2.87	31	31	31
cowpea	1.07	1.06	1.02	31	32	33
sorghum	3.44	3.87	3.73	31	33	35
maize	3.22	3.03	2.61			

[a]) Cowpea received 25 and 50 kg ha^{-1}.

Table 43. Recommended application rates of fertilizer P (kg ha^{-1}) for different crops, in relation to P-Bray-I in the topsoil (0-20 cm). The recommendations refer to band placement of soluble phosphorus fertilizers (triple superphosphate, compound fertilizers). Targets are normative good yields as mentioned in Table 33.

P-Bray-I, mg kg^{-1}	Maize, soybean	Sorghum, groundnut	Cowpea
0-2	100	70	50
3-5	70	40	30
6-15	50	20	10
16-30	30	15	0
> 30	15	0	0

6.5.3.3 Fate of fertilizer P

In the foregoing it was shown that P-Bray-I easily built up in the topsoil upon repeated application of fertilizer P, indicating that Zanderij soils are not P-fixing soils. Further evidence for this comes from some long-term trials (designed for other purposes). Fig. 40 shows that the fraction of recovered fertilizer P as determined by P-Bray-I was 0.15-0.50 after 4 or 6 crops and about 0.13 after 22 crops. The fraction recovered by the crop was approximately 0.15 after a single application and approximately 0.25 after repeated applications. This fraction would probably have been higher if other growth conditions had been optimum.

Movement of P to deeper layers was limited. As far as it occurred, it was caused by deep ploughing rather than by leaching.

Fertilizer P that has not been absorbed by the crop and has not moved to deeper soil layers must show up in the data for total P obtained by analysing the topsoil. To assess its relation to P-Bray-I, total P was analysed in a number of forest and cropped topsoils at Kabo (Fig. 41). Assuming that this relationship is also valid for the Coebiti soils, it can be calculated that the fertilizer P that

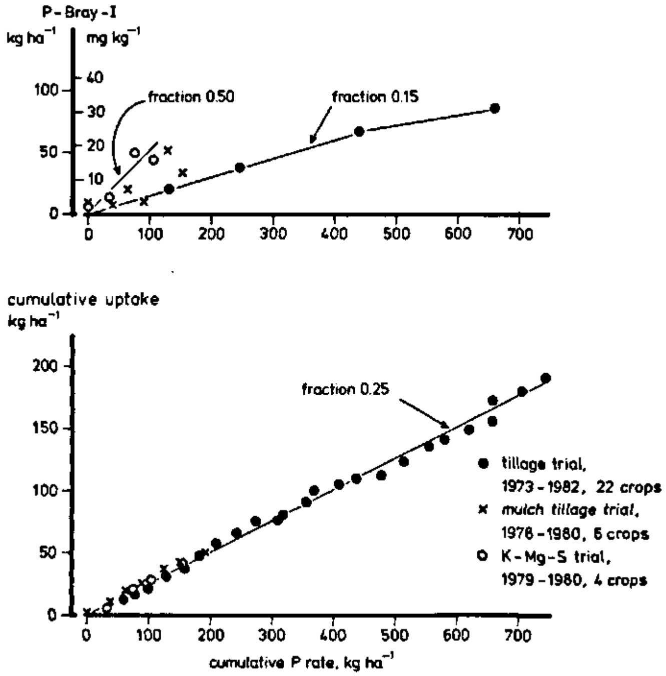


Fig. 40. P-Bray-I (0-20 cm) and cumulative P uptake in relation to the cumulative amount of fertilizer P for some long-term trials at Coebiti.

was not absorbed by the crop remained in the topsoil (Table 44).

At the end of the long-term tillage trial of Fig. 40, however, P- Bray-I in some 20-40 cm samples was around 10 mg kg^{-1}, which points to an enrichment of about 100 kg ha^{-1} P or about 10-15% of applied P. Combining these results into a rule of thumb: in the long run fertilizer P is distributed over crop, topsoil and subsoil in a ratio of 25:65:10. If growth factors are optimum the fraction taken up by the crop might increase to 0.4.

Table 44. Speculative calculations on the fate of fertilizer P for a cumulative P application of 650 kg ha^{-1}.

Cumulative P application, kg ha^{-1}	650
Corresponding crop P uptake (Fig. 40, below), kg ha^{-1}	165
P remaining in soil, kg ha^{-1}	485
Corresponding P-Bray-I (Fig. 40, above), mg kg^{-1}	30
Corresponding total P (Fig. 41), mg kg^{-1}	330
P-Bray-I after clearing (Table 10), mg kg^{-1}	5
Corresponding total P after clearing (Fig. 41), mg kg^{-1}	120
Increase in total P, mg kg^{-1}	210
Ditto, in kg ha^{-1} (0-20 cm; volumic mass = 1.3 Mg m^{-3})	546

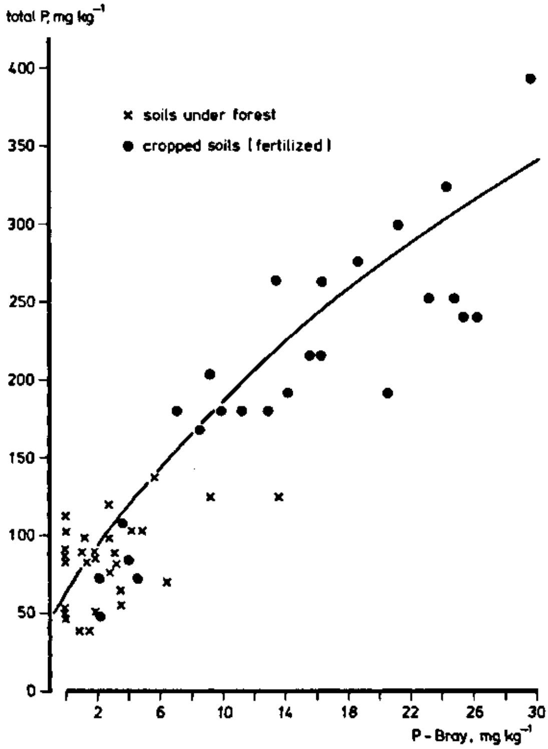


Fig. 41. Relationship between total P and P-Bray-I for topsoils (0-20 cm) from Kabo experimental farm.

6.5.4 Potassium

6.5.4.1 Type and method of application of K fertilizers

In the project, standard K fertilizers were muriate of potash (KCl; 60% K_2O), potassium magnesium sulphate ($K_2SO_4.MgSO_4.6H_2O$; 26% K_2O, 9% MgO) and compound fertilizers containing 12 to 22% K_2O. They were usually split-applied in equal portions; at planting and about four weeks later for leguminous crops; at planting (or one week later), and four and seven weeks after planting for maize and sorghum.

In a trial with various splitting treatments, the standard procedure of three applications seemed a little better than applying in two portions but the differences between the various treatments were not significant. The average response to K application, however, was highly significant, irrespective of the application method (Table 45).

Table 45. Effect of different methods of splitting potassium fertilizer at a total K rate of 100 kg ha^{-1} on maize yields. Coebiti. Soil (0-20 cm) exchangeable K was 0.8 mmol kg^{-1}. After Slaats & Ukkerman, 1983.

Number of applications	Method of splitting	Time of application weeks after planting	Yield t ha^{-1}
0			3.21
2	1/3 + 2/3	1-7	5.15
	2/3 + 1/3	1-7	5.22
3	3 × 1/3	1-5-9	5.67
6	6 × 1/6	1-3-5-7-9-11	5.55

6.5.4.2 Exchangeable K and recommendations for fertilizer K

The response of crops to fertilizer K depended on the level of soil exchangeable K, pH, and yield level, which in turn especially depended on the nitrogen supply. An example of the response is given in Table 46 for a soil low in exchangeable K and with a low pH. Maize yields and K uptake were approximately doubled or quadrupled by 60 kg ha^{-1} K, but still remained rather low. This was probably because of the low pH and other unfavourable conditions in this soil. The maize yield increase brought about by K application was partly caused by an increase in grain size. In some trials 1000-grain masses were determined; they were 160, 176, 178, 179, 280 and 286 g for yields of 0.74, 0.87, 0.94, 1.22, 2.29, 1.93, 2.65 and 2.80 t ha^{-1}, respectively.

A rather different yield response to fertilizer K was obtained on a soil relatively high in exchangeable K and with an optimum pH (Table 47). The difference in maize yield level and response to K between the first and the third seasons was related to the levels of N application, which were 180 and 240 kg ha^{-1}, respectively.

Table 46. Effect of rate of fertilizer K on yields and K uptake of four consecutive crops, and on exchangeable K (0-20 cm) measured at the start of the growing season, just before the next potassium application. Coebiti. Period: January 1979-August 1980. This was a poor soil; pH(H_2O) was 5.0 and pH(KCl) was 4.1

Crop	Yield, t ha^{-1}		Uptake, kg ha^{-1}		Exch. K, mmol kg^{-1}	
	for fert. K, kg ha^{-1}		for fert. K, kg ha^{-1}		for fert. K, kg ha^{-1}	
	0	52[a])	0	52	0	52
cowpea	1.03	1.55	25.5	31.6	0.50	0.48
maize	1.08	2.11	16.8	43.6	0.58	0.65
groundnut	1.70	2.23	17.6	32.4	0.50	0.85
maize	0.80	2.72	10.3	42.9	0.40	0.60

[a]) Average of 50, 60, 40 and 60 kg ha^{-1} K, respectively.

Table 47. Effect of rate of fertilizer K on yields of four consecutive crops, and on exchangeable K (0-20 cm) measured at the start of the growing season, just before the next potassium application. Coebiti. Period: May 1981-March 1983. This was a relatively rich soil; pH(KCl) was 4.6

Crop	Yield, t ha^{-1}			Exch. K, mmol kg^{-1}		
	for fert. K, kg ha^{-1}			for fert. K, kg ha^{-1}		
	30	60	90	30	60	90
maize	4.18	4.60	4.46	1.3	1.3	1.3
soybean	2.92	2.93	2.96	1.1	0.9	1.1
maize[a])	4.76	5.68	6.24	0.6	0.7	0.8
groundnut	3.16	3.30	3.37	0.7	0.8	1.0

[a]) Fertilizer K rates for this crop were 0, 30 and 60 kg ha^{-1}.

The data from Tables 46 and 47 and other sources were used in Fig. 42, which shows the relationships between K uptake and exchangeable K. If K uptake had not been determined, it was estimated by multiplying yields by 0.018, 0.020,

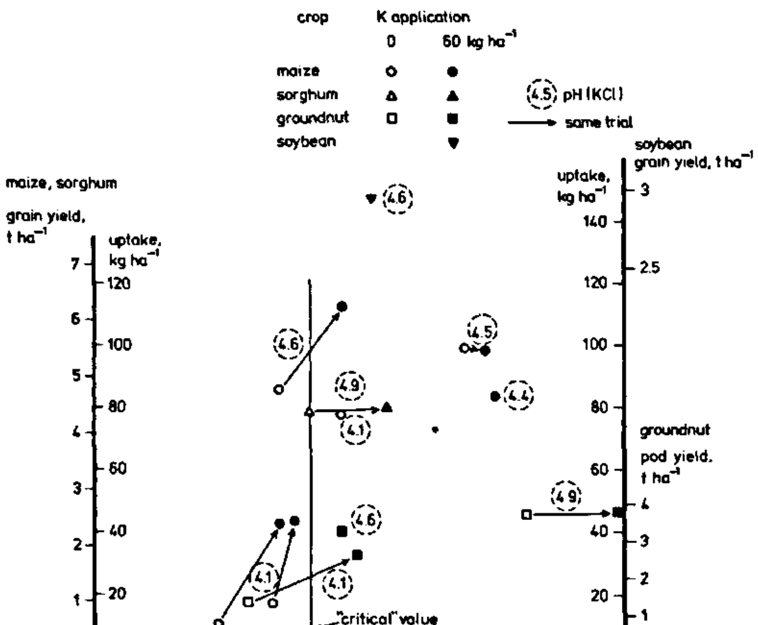


Fig. 42. Yields and estimated K uptake in relation to exchangeable K, pH(KCl) (0-20 cm), and rate of fertilizer K for maize, sorghum, groundnut and soybean.

0.012 and 0.050 for maize, sorghum, groundnut and soybean, respectively. From Fig. 42 it can be deduced that on a soil with 0.6 mmol kg^{-1} exchangeable K, maize is able to take up between 20 and 80 kg ha^{-1} K depending on pH(KCl) and related soil conditions. Although the number of data are limited, it seems justified to conclude that there is a 'critical' value of 0.7 mmol kg^{-1} exchangeable K. At higher values, yields obtained without fertilizer K are at least 90 per cent of those obtained with K, and a K application of 30 kg ha^{-1} is enough for maximum yields (Fig. 43). This 'critical' value holds when pH is in the optimum range.

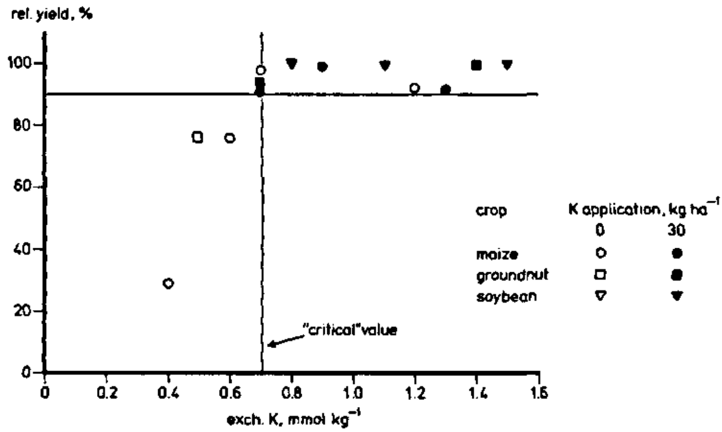


Fig. 43. Relative yields of maize, groundnut and soybean, in relation to exchangeable K in the topsoil (0-20 cm). Crops received no fertilizer K or 30 kg ha^{-1}.

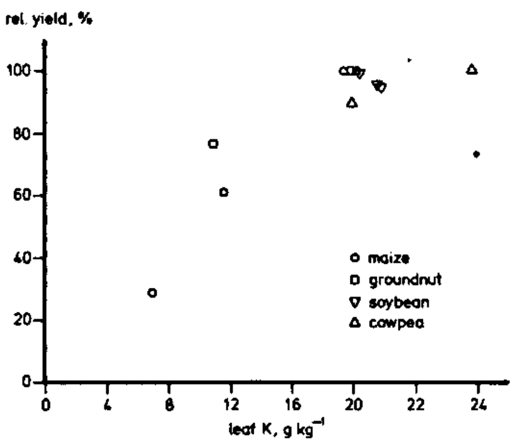


Fig. 44. Relationship between relative yields and mass fraction of K in leaf, for maize, groundnut, soybean and cowpea.

In a number of trials leaf K was analysed. Fig. 44 shows that for all crops used a leaf K mass fraction of 20 g kg^{-1} (= ca. 500 mmol kg^{-1}) was sufficient.

Fig. 42 combined with the data in Tables 33 and 34, forms the basis for the K fertilizer recommendation scheme of Table 48. As will be explained in Section 6.5.4.3, 0.7 mmol kg^{-1} is probably the level of exchangeable K that can be maintained under normal agricultural practices. If soil exchangeable K is lower, part of the fertilizer K is used to increase exchangeable K; if soil exchangeable K is higher, the exchangeable K decreases because of crop uptake and leaching. As a consequence, when exchangeable K is around 0.7 mmol kg^{-1} the amount of fertilizer K should be equal to the removal of K by the crop, or slightly higher to compensate for leaching losses. The rates must be higher or lower, when exchangeable K is lower or higher than 0.7 mmol kg^{-1}.

The recommendations of Table 48 are valid for the first crop after the soil has been analysed. For the following season the application rate required is the same, or is higher or lower than for the first crop, depending on whether the original value of soil exchangeable K was equal to, higher than or lower than 0.7 mmol kg^{-1}.

6.5.4.3 Fate of fertilizer K

The data presented in Tables 46 and 47 were used to estimate from which sources crop K was derived and how the applied fertilizer K was recovered by crop and soil (Table 49). Exchangeable K was expressed in kg ha^{-1}, assuming a bulk density of 1.28 Mg m^{-3} (so, 1 mmol kg^{-1} = 100 kg ha^{-1} for a 20 cm soil layer).

The uptake from exchangeable K was estimated from the decrease in exchangeable K in the control treatment (cf. Table 46) and in the treatment with a cumulative K application of 60 kg ha^{-1}. For the latter treatment, it was assumed that the crop recovered a fraction of 0.5. The extra K uptake in the other treatments was ascribed to fertilizer K. The difference between total uptake and uptake from exchangeable K plus fertilizer K, indicated as uptake from other sources, must have been withdrawn from non-exchangeable K.

The fertilizer K that was allocated to exchangeable K, equals the difference in final exchangeable K between the fertilized and non-fertilized (or fertilized at the lowest rate) soil as shown in the lower half of Table 49. The uptake is the same as in the upper half of Table 49. The K that makes up the difference

Table 48. Recommended application rates of fertilizer K (kg ha^{-1}) for different crops, in relation to exchangeable K (mmol kg^{-1}) in the topsoil (0-20 cm). Targets are normative good yields as mentioned in Table 33.

Exch. K	Maize	Sorghum	Groundnut	Soybean	Cowpea
<0.4	160	120	80	220	60
0.4-0.6	130	100	70	170	50
0.6-0.8	100	80	60	125	40
>0.8	30	20	10	30	10

Table 49. Estimated contribution of several sources to K absorption by three consecutive crops, and apparent fate of fertilizer K, for a poor soil and a relatively rich soil. Data are derived from Tables 46 and 47 and expressed in kg ha^{-1}.

	Poor soil		Relatively rich soil		
Initial exch. K, 0-20 cm	50	50	130	130	130
Total fertilizer K applied	0	150	60	150	240
Total K uptake	60	108	305	332	340
K uptake from					
exch. K, 0-20 cm	10	10	60	60	60
exch. K, 20-40 cm	7	7	n.d.[b])	n.d.	n.d.
other sources	43	43	215	215	215
fertilizer	0	48	30	57	65
Total fertilizer K allocated		150		90[a])	180[a])
K allocated to					
exch. K, 0-20 cm		22		10	30
exch. K, 20-40 cm		29		n.d.	n.d.
crops		48		27	35
other soil components and leaching		51		53	115

[a]) The quantities of 90 and 180 kg ha^{-1} are the differences between the K application rates of 150 and 60 and of 240 and 60 kg ha^{-1}, respectively.
[b]) n.d. = no data available.

Table 50. Estimated partition of fertilizer K applied at a rate of approx. 100 kg ha^{-1} to a soil with exchangeable K (0-20 cm) of approx. 0.7 mmol kg^{-1}.

Fraction of fertilizer K used for	
uptake by crop	0.3 – 0.5
maintenance of exch. K, 0-20 cm	0.1 – 0.2
maintenance of exch. K, 20-40 cm	0.1 – 0.2
other purposes[a])	0.5 – 0.1

[a]) Increase in non-exch. K, increase of exch. K in soil below 40 cm depth, lost by leaching.

between total fertilizer K and K recovered in crop and soil exchangeable K was assumed to have been leached or to have been used for an increase in non-exchangeable K.

The data from Tables 46 and 47 suggest that soil (0-20 cm) exchangeable K can fairly easily increase to about 60 kg ha^{-1} but can also quickly decrease from 130 to 70 kg ha^{-1}. Therefore a value for exchangeable K of 0.7 mmol kg^{-1} (= 70 kg ha^{-1}) is considered as a steady state level that can be maintained if K application compensates for the removal by the crop and some leaching.

A rough estimate of the partition of fertilizer K applied to a soil with a steady-state K level is given in Table 50. If leaching is a considerable fraction of what in the table is called 'other purposes', the soil is not really in a steady state, and exchangeable K will decrease.

Increasing fertilizer K application to rates higher than the recommended rates in Table 48 will lead to a proportionally higher increase in leaching than in uptake of K.

6.5.5 Magnesium

6.5.5.1 Type and method of application of Mg fertilizer

Magnesium was either split applied as potassium magnesium sulphate (K_2SO_4. $MgSO_4.6H_2O$) or compound fertilizers, or given in a single application at or before planting as kieserite ($MgSO_4.H_2O$) or dolomitic limestone (Ca, Mg, $(CO_3)_2$). It was observed that under the prevailing atmospheric humidity small $MgSO_4.H_2O$ crystals easily recrystallized into soluble material, probably $MgSO_4.7H_2O$. Under such conditions kieserite is not therefore to be considered as a poorly soluble fertilizer. As these changes might occur during storage, one

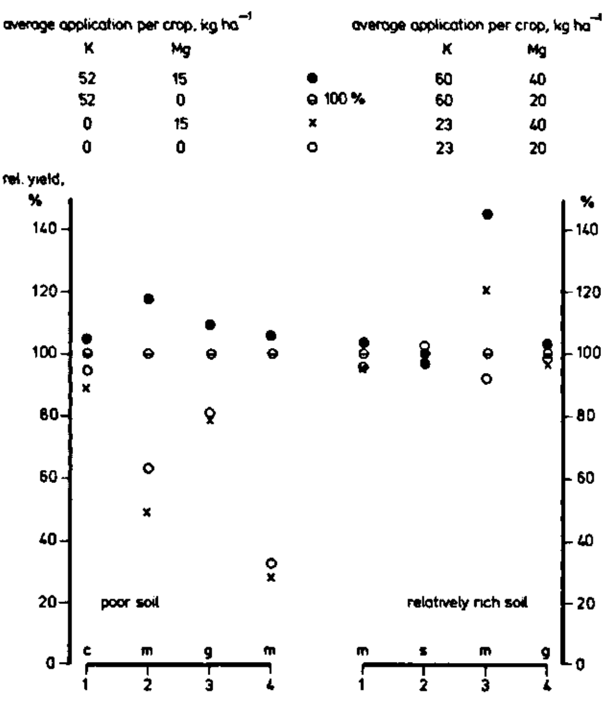


Fig. 45. Effects of K and Mg application on relative yields of four consecutive crops, on a poor soil and on a relatively rich soil. c = cowpea, m = maize, g = groundnut, s = soybean.

should take them into account when weighing the fertilizer for a desired quantity of Mg.

6.5.5.2 Exchangeable Mg and recommendations for fertilizer Mg

Crops responded positively to application of fertilizer Mg in a few cases only (Fig. 45). The poor and the relatively rich soils in Fig. 45 are the same as in Tables 46 and 47. On the poor soil, application of fertilizer Mg resulted in a slight yield decrease if no fertilizer K was applied. On the relatively rich soil, neither K nor Mg had much effect on yield. Only the third crop, maize, showed a positive response to Mg, especially if K was also applied. In this trial, yield and corresponding Mg uptake (22-32 kg ha^{-1}) were high. In most other cases the crop demand for Mg was less than 20 kg ha^{-1}, so that the soil alone could supply sufficient Mg. The maximum Mg uptake from the soil alone was linearly related to exchangeable Mg in the topsoil (0-20 cm), as can be seen from Fig. 46. The relation was:

$$\text{Mg uptake (kg ha}^{-1}\text{ season}^{-1}) = 13 \times \text{exch. Mg (mmol kg}^{-1})$$

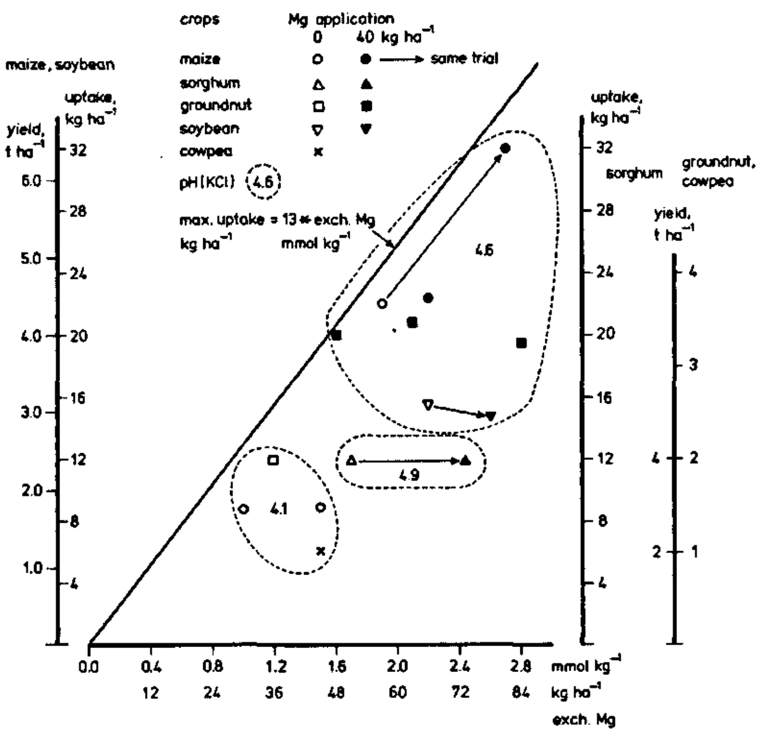


Fig. 46. Yields and estimated Mg uptake in relation to ionic equivalents of exchangeable Mg, pH(KCl) (0-20 cm), and rate of fertilizer Mg, for maize, sorghum, groundnut, soybean and cowpea.

As 1 mmol kg^{-1} of ionic equivalents of Mg roughly corresponds to 30 kg ha^{-1}, the maximum uptake per growing season is estimated at 40 per cent of the amount of exchangeable Mg in the topsoil.

This relationship, combined with the data from Tables 33 and 34, forms the basis for the Mg fertilizer recommendation scheme of Table 51. It was assumed that groundnut recovered a fraction of 0.2, and the other crops a fraction of 0.1 of the fertilizer Mg applied. If exchangeable Mg is just adequate to satisfy the crop's demand, it is recommended to apply Mg at a rate that is about equal to the crop's uptake.

6.5.5.3 Fate of fertilizer Mg

Sources of Mg uptake and distribution of fertilizer Mg over soil, crop and losses were estimated in the same way as explained for K in Section 6.5.4.3. The data on the sources of exchangeable Mg (Table 52) were derived from the same trials as discussed in Tables 46 and 47. From Table 52 it follows that to maintain

Table 51. Recommended application rates of fertilizer Mg (kg ha^{-1}), in relation to ionic equivalents of exchangeable Mg (mmol kg^{-1}) in the topsoil (0-20 cm). Targets are normative good yields as mentioned in Table 33.

Exch.Mg	Maize	Sorghum	Groundnut	Soybean	Cowpea
<0.5	200	50	150	100	30
0.5–1.0	150	30	75	60	10
1.0–1.5	90	10	50	30	0
1.5–2.0	40	0	30	15	0
2.0–2.5	25	0	25	0	0
>2.5	0	0	0	0	0

Table 52. Effect of rate of fertilizer Mg on exchangeable Mg (ionic equivalents, mmol kg^{-1}) on a poor soil (from Table 46) and on a relatively rich soil (from Table 47). Samples were taken shortly before the application of Mg to the next crop. The Mg rates mentioned (kg ha^{-1} per crop) are averages of the rates applied to Crops 1, 2 and 3.

Sampling before crop	Sampling depth, cm	Poor soil		Relatively rich soil		
		fert. Mg, kg ha^{-1}		fert. Mg, kg ha^{-1}		
		0	17	7	27	47
1	0-20	1.5	1.9	2.2	2.2	2.2
	20-40	0.9	1.5			
2	0-20	1.5	2.1	2.2	2.4	2.6
	20-40	0.9	1.2			
3	0-20	1.2	1.9	1.9	2.3	2.7
	20-40	0.9	1.1			
4	0-20	1.0	1.7	1.6	2.1	2.8
	20-40	0.7	1.4			

exchangeable Mg in the topsoil at a level of around 2.0 mmol kg^{-1} (ionic equivalents) an Mg application of 7 kg ha^{-1} per season was not sufficient and a rate of 27 kg ha^{-1} per season was hardly sufficient.

Table 53 is based on the data from Table 52 and on measured or estimated data on Mg uptake. The contribution of fertilizer Mg to Mg uptake was only 4 per cent at low application rates, and around 15 per cent at higher rates. The remainder of fertilizer Mg was used to maintain or increase soil exchangeable and non-exchangeable Mg, or it was lost.

All available data were used in Table 54 to estimate how fertilizer Mg is spent when it is applied at a rate of about 25 kg ha^{-1} per season on a soil with approximately 2.0 mmol kg^{-1} (ionic equivalents) of exchangeable Mg, and when the normative good yields of Table 33 are obtained. Under such conditions a steady state for soil Mg can probably be maintained.

6.5.6 Sulphur

Sulphur was not included in the standard soil and plant analyses, and it did not receive much attention in the studies. The effect of sulphur application was studied in one trial only. It was a K–Mg–S factorial experiment, carried out

Table 53. Estimated contribution of several sources to Mg absorption by three consecutive crops, and apparent fate of fertilizer Mg, for a poor soil (from Table 46) and a relatively rich soil (from Table 47). All data are in kg ha^{-1}.

	Poor soil		Relatively rich soil		
Initial exch. Mg, 0-20 cm	45	57	66	66	66
Total fertilizer Mg applied	0	50	20	80	140
Total Mg uptake	27	28	60	67	70
Mg uptake from					
exch. Mg, 0-20 cm	17	17	18	18	18
exch. Mg, 20-40 cm	6	6	n.d.[b])	n.d.	n.d.
other sources	4	4	40	40	40
fertilizer	0	1	2	9	12
Total fertilizer Mg allocated		50		60[a])	120[a])
Mg allocated to					
exch. Mg, 0-20 cm		9		15	36
exch. Mg, 20-40 cm		4		n.d.	n.d.
crops		1		7	10
other soil components and leaching		36		38	74

[a]) The quantities of 60 and 120 kg ha^{-1} are the differences between the Mg application rates of 80 and 20 kg ha^{-1} and of 140 and 20 kg ha^{-1}, respectively.
[b]) n.d. = no data available.

Table 54. Estimated partition of fertilizer Mg applied at a rate of approx. 25 kg ha^{-1} to a soil with exchangeable ionic equivalents of Mg of approx. 2.0 mmol kg^{-1} (0-20 cm).

Fraction of fertilizer Mg used for	
uptake by crop	0-0.2
maintenance of exch. Mg, 0-20 cm	0.2-0.3
maintenance of exch. Mg, 20-40 cm	0.1
other purposes[a])	0.7-0.4

[a]) Maintenance or increase in non-exch. Mg, and in exch. Mg in soil below 40 cm depth, lost by leaching.

on a poor soil. The results of this trial for K and Mg are presented in Tables 46, 49, 52 and 53, and in Fig. 45. During the four consecutive crops no response to sulphur application was found. It should be realized, however, that the yields in this trial, and hence the demands for sulphur, were rather low.

In none of the trials of the entire project were any symptoms of sulphur deficiency observed. Some of the standard fertilizers applied, such as potassium magnesium sulphate, contained sulphur, and this, in combination with the sulphur supply from the soil, was apparently enough to meet the sulphur requirements of the crops.

6.5.7 Minor nutrients

Minor nutrients were barely studied in the project. To avoid any possible deficiencies of these nutrients the routine practice was to apply 25 kg ha^{-1} fritted trace elements (FTE) once every 2 to 3 years, starting a few years after clearing. The type of FTE used consisted of ground amorphous silicates, acting as a slow-release fertilizer. Expressed in g kg^{-1}, this FTE contained 43 B, 52 Mn, 9 Cu, 85 Zn, 8 Fe and 8 Mo. It is not clear whether the application rate and the composition of the mixture were optimum; however, no symptoms of deficiency of minor nutrients were encountered. This was in contrast to what was reported by Schroo (1976); he found zinc deficiency on Zanderij soils, especially on those low in soil organic matter.

The experiments on minor nutrients carried out during the project gave the following results:
- no response or only a slight positive response in maize or mungbean to FTE application;
- application of Mo increased N concentration in soybean leaves, but this was not accompanied by an increase in yield.

6.6 Relationships between water and nutrients

In Section 6.2.2 it was shown that the crop's response to moisture stress was affected by the level of fertilizer application, and in Section 6.5.2.2 that moisture stress was involved in the variation in the response to fertilizer N under rainfed conditions. These interrelationships will now be discussed in more detail.

6.6.1 Interactions of fertilizer rates, moisture deficit and sunshine duration

In the irrigation trial discussed in Section 6.2.2, fertilizer rates varied from cycle to cycle, for all nutrients applied (Table 18), making interpretation of the results difficult. Therefore, interpolated yields were compared at standard fertilizer rates. A disadvantage of that procedure is that the interrelations between moisture and nutrient availability were not revealed.

To study these relationships, four classes of fertilizer nutrients (relative fertilizer application rates) were distinguished (Table 55). The standard rates used in Section 6.2.2 correspond with relative fertilizer rates of 0.55 and 0.6 for maize and soybean, respectively. The calculated data on moisture deficit (Tables 19 and 20) were used to evaluate moisture availability. The number of stress days may well have been a better criterion, but these data were not available for the irrigated crops. Classes of moisture deficit were 0, 20, 40, 90 and 200 mm for maize, and 0, 20, 90, 135 and 200 mm for soybean. It proved useful to distinguish classes of relative sunshine duration too: 0.38, 0.48 and 0.77 for maize, and 0.5 and 0.75 for soybean.

Maize. Fig. 47 shows that maize yields increased with fertilizer application rate if the moisture deficit was 20 mm or less, whereas beyond a relative application rate of 0.4 no yield increase was obtained if the moisture deficit was 40 or 90 mm. At 200 mm moisture deficit there was virtually no yield, nor was there a response to fertilizers (see Tables 19 and 20, Cycle 3). Irrespective of the fertiliz-

Table 55. Relative fertilizer rates and corresponding average rates of N, P, K, and Mg for maize and soybean in the irrigation trial at Coebiti (rounded figures).

Rel. fertilizer rate	Average rate, kg ha^{-1}			
	N	P	K	Mg
Maize				
0.25	60	25	25	20
0.40	90	35	50	40
0.75	165	65	90	75
1.00	210	75	140	110
Soybean				
0.20[a])	13	20	25	15
0.40	8	35	50	30
0.75	15	65	90	90
1.00	10	65	135	150

[a]) N was not included in the calculation of the values of relative fertilizer rates for soybean.

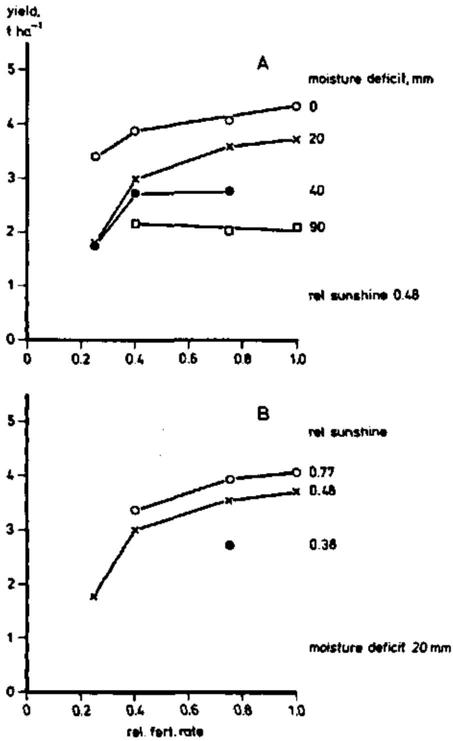


Fig. 47. Relationship between maize yields (t ha^{-1}) and relative rate of fertilizer. A. Effect of moisture deficit. B. Effect of relative duration of sunshine.

er application rate, when relative sunshine was 0.77 yields were about 0.4 t ha^{-1} higher than when relative sunshine duration was 0.48 (Fig. 47). The yield difference brought about by an increase in relative sunshine from 0.38 to 0.77 was about 1.2 t ha^{-1}, which is 30 per cent of the highest yield of 4.1 t ha^{-1}. The theoretical potential yield calculated in Section 6.1.1 (Curve A in Fig. 20) fluctuated between 4.3 and 6.4 t ha^{-1}. In other words, here too the largest difference was about 0.3 times the maximum yield. Unfortunately, the data were too limited for a closer examination of the interrelations between sunshine duration and availability of water and nutrients.

Soybean. The response of soybean to increased fertilizer application was clear at moisture deficits of 0 and 20 mm, weak at a deficit of 90 mm, and absent at the higher levels of moisture deficit (Fig. 48). At 20 mm moisture deficit, sunshine had a modest positive effect. Yield levels were higher at 20 mm than at 0 mm moisture deficit. This is probably accidental; most data in the zero moisture deficit class are from Cycle 2 (Table 20), when soybean had to be resown because of poor emergence.

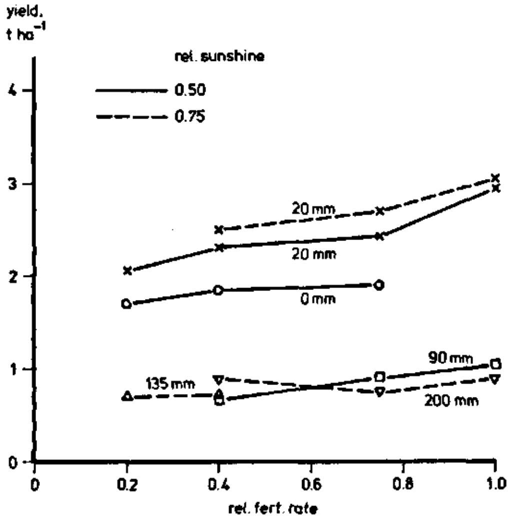


Fig. 48. Relationship between soybean yield (t ha^{-1}) and relative rate of fertilizer as affected by moisture deficit and relative duration of sunshine. Figures alongside the curves indicate moisture deficit (mm).

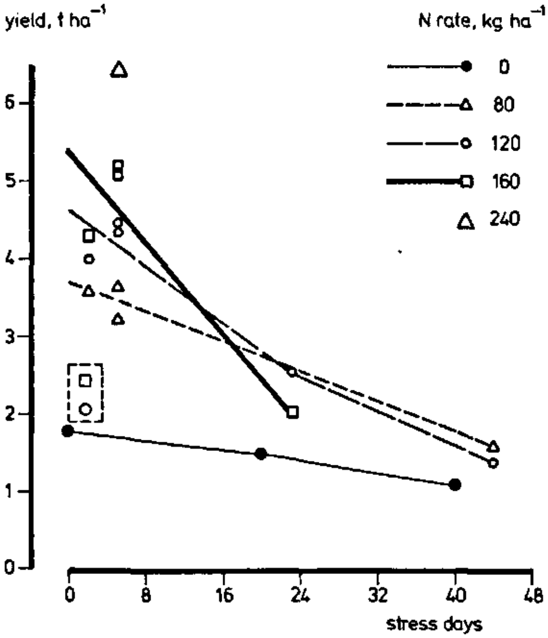


Fig. 49. Maize yields as related to number of stress days during the critical period and to N application. Curve for no nitrogen fertilizer found by extrapolation in Fig. 36. Points in rectangle are from Trial 8, in which yields were low because of paraquat damage.

At moisture deficit levels of 90, 135 and 200 mm, yields were virtually equal. It is possible that more sunshine counterbalanced the effects of more severe drought in the 135 and 200 mm classes. However, there were insufficient data to be able to unravel these effects.

In conclusion, both Fig. 47 and Fig. 48 show that optimum fertilizer application rates decrease as moisture deficits increase. This implies that fertilizer recommendations should be modified, depending on planting date.

During the project sufficient experimental information for this was only obtained for nitrogen. However, the interrelationship with moisture is probably more obvious for nitrogen than for other nutrients.

6.6.2 Moisture stress and response to N by cereals

6.6.2.1 The effect of moisture stress

Fig. 36 shows that the N rates at which yield response changed from positive to negative varied from 80 kg ha^{-1} to more than 250 kg ha^{-1}. To investigate the influence of moisture the number of stress days during the critical period (36-85 days after planting) was calculated with the model discussed in Section 6.1.3. This could be done for the Coebiti trials only (Table 37). Fig. 49 shows that stress days clearly depressed yields, the slopes of the curves being steeper with higher N application rates.

Based on the relationships shown in Fig. 38 and Fig. 49, a schematic three-quadrant diagram was designed for 0, 10, 20 and 40 stress days (Fig. 50). It shows that control yields, N utilization, N recovery, and optimum N application rates were all negatively affected by moisture stress. The quantity of N taken up from the soil alone as found by extrapolation was estimated to be 35 kg ha^{-1} in all cases. The available data were not sufficient to make a distinction between stress periods.

6.6.2.2 Fertilizer-N recommendations for maize

The influence of moisture stress on crop response to fertilizer N has far-reaching implications on the profitability of N use and on the recommendations made for fertilizer N. The latter should take into account the number of stress days expected.

In 1983 the price of 1 kg urea-N was about one Suriname guilder (SRG 1.00) whereas the price of maize fluctuated between SRG 0.25 and SRG 0.40. To be economic, maize yield increases should exceed 2.5 to 4 kg per kg urea-N applied.

Yield increases per kg N ($\Delta Y / \Delta F$) were calculated from Fig. 50 for N rates over the intervals of 0-80, 80-120, 120-160 and 160-240 kg ha^{-1}. The results thus obtained were plotted versus N rate for 0, 10, 20 and 40 stress days during the critical period (Fig. 51). The intersections of these curves with the horizontal

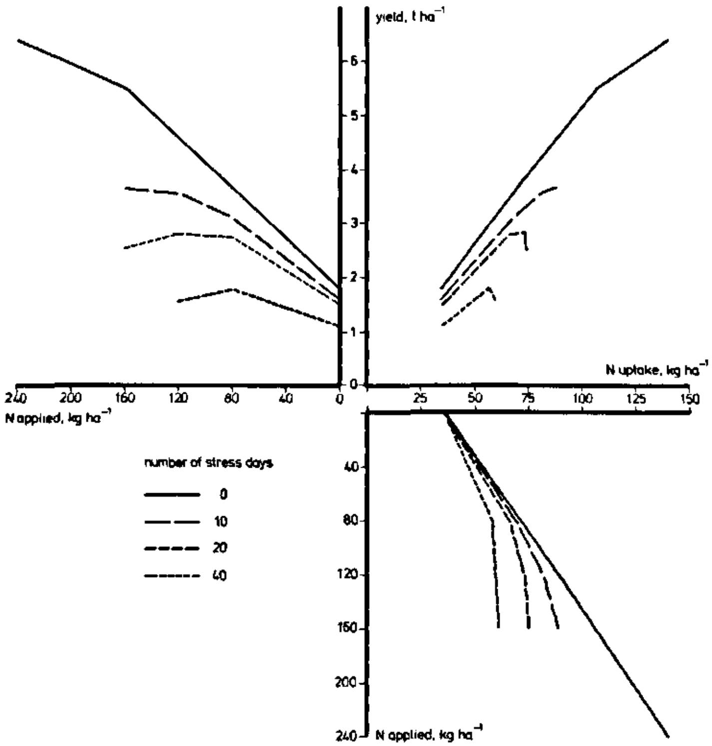


Fig. 50. Schematic relationships between N application, N uptake and maize yield for 0, 10, 20 and 40 days of moisture stress during the critical period.

lines, representing $\Delta Y / \Delta F$ values of 4 and 2.5, indicate the approximate economic optimum N application rates. They were 250, 140, 90 and 60 kg ha^{-1} for 0, 10, 20 and 40 stress days, respectively.

Next, the numbers of stress days for successive planting times were averaged for the years 1977-1982. They are shown in Fig. 52, together with calculated control yields, yields at optimum fertilizer N rates and corresponding $\Delta Y / \Delta F$. April was clearly the best time to sow maize.

In the period 1977-1982 the number of stress days differed considerably among the years. Table 56 gives the extremes in the number of stress days, optimum N rates and expected yields for March, April and May plantings.

To account for the variation in number of stress days, it is recommended to plant maize in April, and to apply N in two applications of 85 kg ha^{-1} each (e.g. at planting or somewhat later, and at 30 days after planting), whereas a third application (ca. 45 days after planting) might vary from 0 to 80 kg ha^{-1}, depending on weather conditions. The normative good yields of 4.5 t ha^{-1}, or higher, can then be obtained.

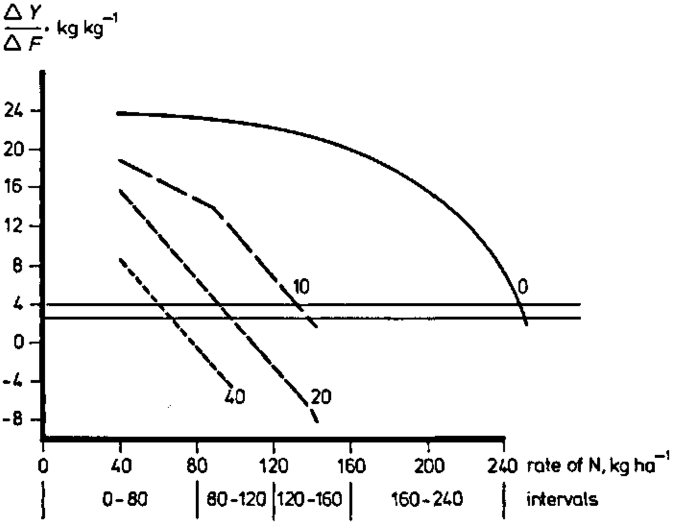


Fig. 51. Slope of the yield - N rate curve ($\Delta Y/\Delta F$) in relation to N rate, for 0, 10, 20 and 40 moisture-stress days during the critical period. For explanation see text.

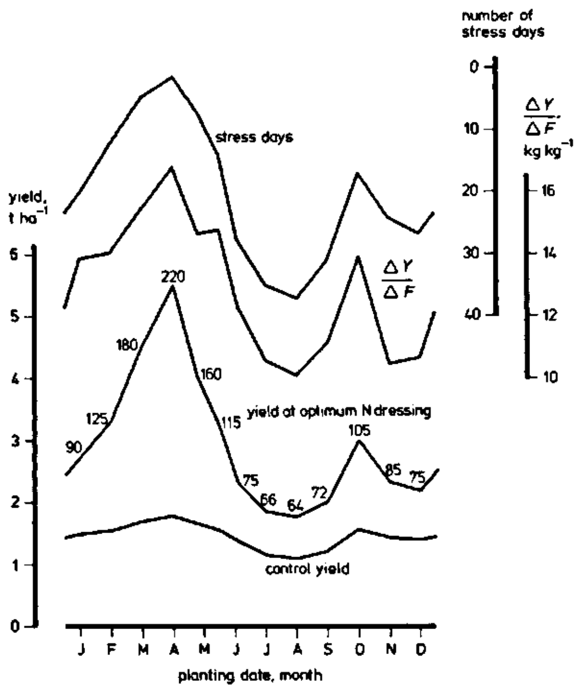


Fig. 52. Average number of calculated stress days during critical period of maize planted at the indicated time, over the years 1977-1982. Coebiti. Corresponding control yields, yields at optimum N rates (figures refer to optimum N rate in kg ha^{-1}) and slope of the curve of yield versus N rate ($\Delta Y/\Delta F$).

Table 56. Highest (1) and lowest (2) number of calculated moisture-stress days during the critical period of maize planted in the period March - May, as found for Coebiti over the years 1977-1982, and corresponding optimum N rates (kg ha^{-1}) and related yields.

Period	Stress days		Optimum N rate[a])		Yield, t ha^{-1}[b])	
	1	2	1	2	1	2
8-31 March	11	0	135	250	3.5	6.5
1-28 April	6	0	170	250	4.3	6.5
29 April - 12 May	15	0	110	250	3.1	6.5
12-25 May	21	0	90	250	2.6	6.5

[a]) Found by interpolation of Fig. 51.
[b]) Found by interpolation of Fig. 50.

The lack of meteorological data for Kabo prevented the number of moisture stress days from being calculated, and hence the above relationships were not tested for that site. However, although the number of stress days and their distribution over the year may differ, there is no reason to assume that the relationships would differ from those found for Coebiti.

6.7 Pests and diseases

6.7.1 *Insect pests*

6.7.1.1 *Establishment*

The insect fauna in the forest before clearing was surveyed at Kabo only. Yellow pans and Malaise traps were used. This survey did not yield species known as pests of annual crops.

After clearing, *Digitaria horizontalis*, one of the very few early pioneer weeds, was injured by the Hesperid *Nyctelius nyctelius*. Some caterpillars of this species were also seen on seedlings of the first crop planted at Kabo, i.e. maize. A few days later the same maize crop became heavily infested with *Spodoptera frugiperda* (Noctuidae). Such a heavy attack had never been observed at the Coebiti farm. The crop had to be resown. No light traps being available, it did not become evident whether the adult population came from the surrounding forest, from the road verges or from further away.

Later, unexpected or unknown pests occurred. *Trigona* bees gnawed holes in ripe cowpea pods exposing the seeds to the influences of weather and fungi. These bees are known as pests of yardlong bean in the coastal area but not of cowpea. Tiny Lepidopterous larvae tunnelled the stems of soybean seedlings causing half the number of plants to die. These pests disappeared at harvest or when the attacked plants died, and never damaged crops again. Obviously, the ecosystem was extremely unstable so that insect populations were able to increase without being checked by predators or parasites.

At Coebiti, leaf-cutting ants (*Atta* sp.) occasionally damaged annual crops. Damage was usually confined to rows near the forest surrounding the experimental farm, or near perennial crops or fallow ground that had not been recently cultivated, allowing ants to establish nests. Mirex bait (a.i. dodecachlor) applied near the entrances of the ants' nests was effective in eliminating the colonies.

Mole crickets (*Scapteriscus* and *Gryllotalpa* spp.) are a major pest in the coastal area of Suriname but not at Kabo or Coebiti, although adults were caught in black-light traps. It may be that the Zanderij soils have properties unfavourable to their burrowing way of life.

6.7.1.2 Cereals

The typical leaf damage by 'the fall army worm' (*Spodoptera frugiperda*, Noctuidae) gave the impression that this pest was a factor limiting maize production. Treatment with insecticides such as permethrin (0.2 litres Ambush 50 e.c. per ha), monocrotophos (1 litre Azodrin 600 g l^{-1} per ha), trichlorphon (1 kg Dipterex SP 95 per ha), fenitrothion (1 litre Sumithion 50 per ha) or methomyl (1.5 litres Lannate per ha) much reduced and sometimes even prevented damage to the leaf whorl. However, the yields were not significantly higher than in control plots.

Carbofuran (25 kg Furadan 5G per ha) applied under the seed at planting reduced seedling damage by arthropods and ensured a good crop, but when climatic conditions were unfavourable for maize cultivation, plots treated with carbofuran were found to yield significantly less than control plots.

Injury to the stalks caused by stem borers (*Diatraea* spp.) could not be prevented with insecticides. The effect of borer infestation was not clear. In one experiment the percentage lodging was the same for borer-free plants and for borer-infested plants. No correlation was found between borer incidence and maize yield, but borers could cause 'dead hearts' in sorghum. *D. saccharalis* and *D. lineolata* were reared from maize but *D. centrella* was only caught in traps at Coebiti and Kabo. Ear damage by corn earworm (*Heliothis zea*, Noctuidae), stem borers and fall army worm could not be avoided, in spite of weekly applications of Lannate or Ambush.

Other pests were corn leaf aphids (*Rhopalosiphum maidis*), chinch bugs (*Blissus leaucopterus*) and *Mocis latipes* (?) (Noctuidae). These pests were considered of minor importance, although at times *Mocis* larvae completely defoliated maize plants after first having defoliated grasses and Cyperaceae present near or in the maize fields.

Once, a heavy attack of *Mocis* at Kabo was accompanied by an outbreak of what looked like *Spodoptera*. Larvae of the latter were found in large numbers per plant and defoliated the crop, starting with the oldest leaves (usually, only one caterpillar is present per plant, in the whorl). The adults were very similar to *Spodoptera* adults collected at other times – except that the males were slightly more brightly coloured. No differences in male genitalia were observed and it was concluded that the species concerned was *Spodoptera frugiperda* although this population showed an aberrant behaviour.

Parasitism was not an important factor in larvae mortality. Only three parasites, belonging to two species of Tachnidae (Diptera) were reared from over 100 *Spodoptera* larvae collected in the field. Only three of the over 50 *Diatraea* larvae examined were parasitized, by *Stomatodexia diadema* (Tacnidae). *Polistes* wasps were always present in maize crops, searching the plants for caterpillars. Predation was therefore probably more important than parasitism.

Although the yield of insecticide-treated maize was sometimes higher than that of non-treated maize, insecticide application is not considered to be economically feasible.

6.7.1.3 Legumes

A survey of the insect pests occurring in the legumes is given in Table 57. Attacks by Cicadellidae, characterized as 'hopper burn', caused a light green to yellow discolouration near leaf edges. In soybean and cowpea (but not in groundnut) the leaves wrinkled. The attack resulted in stunted growth, a faded appearance and low yields. In one experiment with groundnut, a pre-planting application of carbofuran (40 kg Furadan 5G per ha) prevented leafhopper damage. Compared with treated plants the main stem of control plants was 22 per cent shorter, and yields were reduced by about one-third (Fig. 53). A rainfall distributed evenly over the growing season may explain the explosive increase in the leafhopper population that was experienced in this particular experiment. In later experiments the populations were never as high and the effect of carbofuran was negligible.

Leaf-feeding beetles (Chrysomelidae) can cause severe loss of leaf area in soybean grown in the coastal plain. In the Zanderij area damage was only observed occasionally. Higher infestation rates were found in plots where weeds were present. The genera *Cerotoma* and *Diabrotica* are the main pests of cowpea in the coastal plain. At Coebiti, chrysomelid beetles were found defoliating cowpea plants in a small field experiment, but in larger fields crop injury was never serious.

Table 57. Insect pests[a]) reported for legumes in the Zanderij area.

	Soybean	Groundnut	Cowpea	Mungbean
Cicadellidae	x	xx	x	
Chrysomelidae	xx		x	
Anticarsia gemmatalis	x	x		
Heteroptera	x		x	x
Hippopsis lemniscata	x			
Stegasta basquella		x		
Spodoptera frugiperda		x		
Maruca testulalis			x	
Frankliniella sp.			x	
Aphis craccivora			x	

[a]) x = no or minor damage; xx = severe damage.

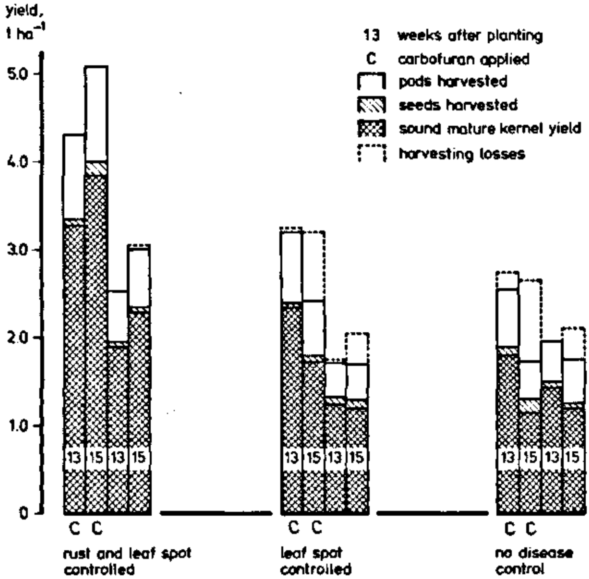


Fig. 53. Effects of leaf-spot disease, rust and leafhopper control on yield and harvesting time (weeks after planting) of groundnut.

Velvet bean caterpillars (*Anticarsia gemmatalis*, Noctuidae) sometimes occurred in soybean. The larvae have been reported to feed on groundnut, but at Kabo and Coebiti damage was never observed, although adults were often caught in light traps.

Bugs (Heteroptera) sometimes occurred in soybean, and were present in cowpea but in numbers too low to cause damage. They were observed in mungbean flowers, stems and young pods.

Once an attack by a Cerambycid beetle was observed on young soybean plants about 15 cm high. Larvae tunnelled the stems and many plants died. Adults were 9-12 mm long, 0.8-1.0 mm wide and greyish brown with brownish-yellow longitudinal stripes. Antennae were about three times the body length. No reference to this pest was found in the available literature. The insect was identified as *Hippopsis lemniscata* by M. Russel, British Museum (Natural History), London.

The rednecked peanut worm, *Stegasta basquella*, was often observed in groundnut at Coebiti and Kabo. Young, still folded leaflets were perforated, giving rise to symmetrical holes in the four leaflets of a leaf after unfolding. This pest is not considered to be of any economic importance.

Larvae of *Spodoptera frugiperda* were often caught in light traps, but no damage was ever observed in groundnut.

Wherever in the world cowpea is grown, insect pests such as the Pyralid *Mar-*

uca testulalis and flower thrips are reported as being important pests. *Maruca testulalis* was caught in large numbers in light traps at Coebiti and Kabo. Adults were reared from pigeon pea pods. Occasionally larvae were encountered in cowpea flowers but not in pods. About 40 per cent of the trees in the nearby forest are Leguminosae, and these trees may be preferred host plants; this could explain why this insect is not a pest of cowpea in the Zanderij area.

Flower thrips (*Frankliniella* sp.) were sometimes present but the crop losses caused by this pest could not be assessed. In experiments at Kabo and Coebiti no differences in yield were observed when cowpea cultivars were treated with monocrotophos (Azodrin 5) at different stages. In one experiment at Kabo fairly large numbers of thrips were present in the cultivar TVx 66-2H and only a few in TVx 13-31K. Yields were 451 and 341 kg per ha respectively. At Coebiti the yields were about 200 kg per ha for either cultivar. Severe drought soon after planting is the main explanation for this low yield.

The cowpea aphid, *Aphis craccivora*, was found once in large numbers on seedlings and young cowpea plants.

6.7.1.4 Root and tuber crops

Common cassava pests were present at Kabo, but their origin is not known. It is possible that they were introduced from Coebiti when plant material was transferred. Adults of the cassava hornworm (*Erinnyis ello*) were caught quite often in areas where hitherto no cassava had been grown; this suggests that the pest may have been present in the original vegetation.

The following pests were found in cassava at Kabo: thrips (*Corynothrips stenopterus*), scale insects (Coccoidea), lace bug (*Vatiga* sp.), *Phlyctaenodes bifilalis* (Pyralidae), *Jathrophobia brasiliensis* (Cecidomyidae), *Carpolonchaea chalybea* (Lonchaeidae) and *Mononychellus tanajoa* (Acari). Damage was considered to be minor and no control measures were taken. Application of thrichlorphon (Dipterex SP 95) may check heavy attacks.

Sweet potato tubers were often infested by the West Indian sweet potato weevil (*Euscepes postfaciatus*). The tubers were tunnelled just below the peel, thus affecting quality and not production.

Cylas spp., commonly called sweet potato weevil and known to be an important pest in neighbouring countries, were not found at Coebiti or Kabo.

6.7.2 Diseases

6.7.2.1 Cereals

Leaf blight, caused by *Helminthosporium* sp., was a common disease of maize. Its effect on yield is not known. In places with waterlogging *Pythium* sp. caused plant losses. It was not of importance where natural soil drainage was good.

Several fungi (*Diplodia* sp. and *Gibberella* sp.) caused ear rot. Whether insect-damaged ears were more susceptible to infection by ear rot fungi remains to be established.

Sorghum panicles maturing during humid rainy conditions readily became infected by grain moulds and head blight. Cultivars with open panicles that dry more quickly after rain are likely to be less susceptible than cultivars with closed panicles. The predominant fungus causing these diseases was *Curvularia* sp., often accompanied by *Colletotrichum graminicola* and *Exserohilum* (= *Helminthosporium*) *turcicum*, all of which were also present on the grains. Seedlings from such infected planting material showed delayed growth and often died soon after emergence. The first symptoms consist of small reddish spots on leaves and leaf sheaths. Sometimes the kernels in affected panicles germinated on the plant, but whether this was induced by moisture or by the fungi, could not be established.

Fully grown plants were often attacked by fungi, *Colletotrichum graminicola* mainly, causing necrotic spots in red-brown stripes on leaves and stalks. *Curvularia* sp. and *Exserohilum turcicum* were also present. As a result leaves died prematurely. The disease was most pronounced after flowering.

6.7.2.2 Legumes

Soybean and mungbean did not suffer much from diseases, cowpea only occasionally, but for groundnut the main yield-reducing factors were leaf-spot diseases and rust. Table 58 summarizes the diseases found in legumes on the Zanderij soils.

Research at Coebiti in 1974 indicated that leaf spot diseases caused by *Cercospora arachidicola* and *Cercosporidium personata* suppressed yields by 37 per cent (Bink, 1975). Rust, caused by *Puccinia arachidis*, was not a yield-reducing factor then and groundnut was sprayed with fungicides such as benomyl, which controlled leaf spot diseases only. As a result, rust became an increasing problem.

In five field experiments at Coebiti chlorothalonil (3.5 l Bravo 500 e.c. per ha) proved to be the best fungicide, controlling both leaf spot disease and rust adequately. It should be applied at 14-day intervals, starting 3 weeks after planting. Benomyl (0.5 l Benlate w.p. per ha) and thiophanate-methyl (0.5 l Topsin M per ha) only controlled leaf spot diseases, whereas maneb (3 kg Maneb w.p. per ha) was effective against rust. Compared with chlorothalonil, a mixture of benomyl or thiophanate-methyl and maneb was less effective against leaf spot

Table 58. Diseases[a]) reported for legumes in the Zanderij area.

	Soybean	Groundnut	Cowpea	Mungbean
Seedborne diseases	x			
Leaf-spot diseases		xx		x
Rust		xx		
Soilborne diseases		x		
Choanephora sp.			xx	
Colletotrichum sp.			x	
Fusarium			x	

[a]) x = no or minor damage; xx = severe damage.

and rust, but could nevertheless be used as an alternative to chlorothalonil.

Adequate leaf spot and rust control lengthened the life span of the leaves; when harvested, plants still had all their leaves. The groundnut cultivar Matjan required 105-115 days to reach harvest maturity (75 per cent of pods mature).

When diseases were properly controlled, 3 t ha^{-1} was a normal yield, but yields of 5 t ha^{-1} were obtained with Matjan if leafhopper was also controlled and harvest was 15 weeks after planting (Fig. 53). If diseases were poorly controlled plants started shedding their leaves much earlier. Postponement of harvest then caused loss of yield because the pegs broke when lifting the plants (Section 8.3.2.4). With adequate disease control, the quality of the seed was very good. By harvesting some days after harvest maturity, more pods reach maturity, so increasing yield.

From these experiments it is concluded that even in the long rainy season plants can be kept virtually free from leaf diseases. Other cultivars with a growing cycle longer than Matjan can therefore be grown successfully. As cultivars of the runner type of groundnut can be harvested mechanically more easily than the Spanish type Matjan, and as fungicide application by tractor-mounted sprayer is as effective as application by knapsack sprayer, a considerable expansion of the area planted to groundnut is possible.

Soilborne pathogens such as *Sclerotium rolfsii* were only found occasionally in groundnut. Whether the soil properties adversely affected the survival of these pathogens remains to be established. The use of good quality, undamaged seed treated with thiram, prevents losses caused by *Aspergillus niger*.

Cercospora leaf spot was present in mungbean but fungicide application did not increase yields.

As a routine, soybean seed was treated with fungicides such as thiram but the percentage emergence could nevertheless be low. Seedborne fungal diseases seemed to be of minor importance amongst factors influencing germination. For soybean production, control measures other than seed treatment are not considered necessary.

Fungal diseases in cowpea were of minor importance except perhaps for *Choanephora* sp. and saprophytic fungi that attacked ripe pods and caused loss of quality when the crop matured during a period of little sunshine and high air humidity. Application of captan seemed to limit the damage. Maneb, thiophanate methyl (Topsin M) and copper-II-oxide (Kocide) were less effective. As not all pods mature simultaneously, harvesting should be scheduled for the dry season, to ensure good quality seed. When pods are picked by hand, harvesting should be done in two or three rounds. Anthracnose (*Colletotrichum* sp.) was observed in variety trials, affecting the stems, leaves and pods of only a few cultivars. At Coebiti, *Fusarium* wilt was regularly observed, killing individual plants in various stages of development. The disease was very pronounced in a rotation experiment where cowpea was planted four times in succession on the same plot. At Kabo, however, monocropping of cowpea during ten cycles in three years did not lead to this disease.

6.7.2.3 Root and tuber crops
In cassava, leaf spot disease (*Cercospora* sp.) was observed, but it is not considered to be of great importance.

6.7.3 Nematodes

Plant parasitic nematodes were found in soil samples collected in the forest at Kabo. *Helicotylenchus erithrinae*, *Peltamigratus luci*, *P. holdemani*, *Discocriconemella limitanea*, or *D. glabrannulata* (?), *D. mauritiensis*, *Macroposthonia onoensis*, *Paratrichodorus westindicus*, *P. minor*, *Xiphinema ensiculiferum*, *X. paritaliae*, *X. surinamense*, *X. vulgare* and *X.* cf. *imambaksi* were identified (P.A.A. Loof, Dept. of Nematology, Wageningen Agricultural University). *Meloidogyne* larvae and *Discocriconemella* spp. predominated, with average numbers of 120 and 45 per dm^3 of soil (0-10 cm), respectively, using the Seinhorst two-Erlenmeyer extraction technique. Saprozoic nematodes were found in comparatively large numbers – on an average about 6500 per dm^3 of soil (0-10 cm). Their numbers decreased sharply with depth and almost no nematodes were found below 20 cm. The average number of saprozoic nematodes in the top 20 cm was about 3400 per dm^3 of soil.

A study early in 1979 revealed that clearing decreased the nematode density. Besides the plant parasitic species mentioned above, *Tylenchorhynchus* sp. was now found in forest soil samples. Numbers were slightly higher on hand-cleared land than on mechanically cleared land (Table 59). Physical influences of climate on bare soil might have caused the nematode populations to decline and the plant parasitic nematodes to disappear in a short time immediately after clearing. Burning the felled vegetation further increased the decline.

At Coebiti a survey was carried out at about the same time as the survey at Kabo (Table 60). The species present under annual crops at Coebiti were not found under undisturbed forest or in cleared land at Kabo, suggesting that they were introduced with planting material, agricultural machinery, etc. But

Table 59. Influence of clearing methods on nematode fauna composition (numbers per dm^3) of the topsoil (0-10 cm). Kabo.

	Forest	Clearing method			
		mechanical		by hand	
		burnt	not burnt	burnt	not burnt
Tylenchorhynchus sp.	130	0	0	0	0
Helicotylenchus erithrinae	40	0	0	0	0
Meloidogyne larvae	230	10	20	30	30
Criconematidae	20	0	0	10	10
Xiphinema spp.	10	0	0	20	10
Saprozoic nematodes	4410	1320	2340	2350	3150

Table 60. Incidence[a]) of plant parasitic nematodes after four occupations of the same crop. Coebiti.

Nematode	Maize	Sorghum	Soybean	Groundnut	Cowpea	Mungbean
Pratylenchus brachiurus	++	++	+	+	+	+
P. zeae	+	–	+	+	–	–
Rotylenchulus reniformis	–	–	++	–	++	+
Macroposthonia ornata	+	++	+	+	+	+
Meloidogyne spp.	+	+	+	+	+	++

[a]) ++ = predominant; + = present; – = not detected.

because the plots were heavily infested with weeds (mainly *Eleusine indica*), Table 60 does not give an exact picture of the nematode–crop associations.

In a field experiment with groundnut, lesion nematodes, *Pratylenchus brachiurus*, reduced pod quality by causing blueish spots. Rainfall was evenly distributed over the growing season. Carbofuran, applied at planting and 3 weeks later, controlled this pest but with bandplacement pod damage was only prevented in the treated part of the soil, suggesting contact rather than systemic action against nematodes.

6.8 Weeds

This section merely summarizes the work on the occurrence and control of weeds, and on the competition between crops and weeds. A complete and detailed description of this work is presented elsewhere (Everaarts, 1990).

6.8.1 First weeds

6.8.1.1 Coebiti

It is not certain whether weed species known to occur at Coebiti now, were already present in the area before clearing and cultivation, because no relevant information is available on the vegetation prior to clearing. Typical agricultural weeds, however, do not occur in undisturbed rainforest. Nevertheless, some weeds or wasteland plants may have been present in or near the Coebiti farm area before clearing, as Coebiti was cleared from exploited forest; furthermore, the opening of the Zanderij belt by the construction of a road system in the 1960s may have facilitated the entrance of plants formerly foreign to the area. Also some weeds or wasteland plants may have been present on nearby savannas or on shifting cultivation plots or ruderal sites in or close to the nearby Amerindian village of Bigi Poika.

Hoving (1973) reported very little weed growth in his 1972 experiments, three years after clearing, except for some places in groundnut and mungbean plots where several grasses appeared. No identities of weeds were given, however. Van Muijlwijk (1974a) noted that in a 1973 groundnut experiment much trouble was caused by weeds, especially grasses (*Digitaria* spp.). Broadleaved weeds like *Physalis* sp. were present but not to a serious degree. In another experiment the same year (Van Muijlwijk, 1974b), weed occurrence was low and weed growth consisted mainly of *Borreria latifolia*, and also of *Physalis angulata* and *Croton trinitatis* (cited as *C. miquelianus*). In wet places Cyperaceae dominated.

Budelman & Ketelaars (1974) identified weeds at Coebiti in late 1973 or early 1974 and listed the following species: *Andropogon bicornis*, *Borreria latifolia*, *Digitaria* cf. *horizontalis*, *Euphorbia thymifolia*, *Lindernia crustacea*, *Ludwigia erecta* (cited as *Jussieua erecta*), *Mariscus ligularis*, *Physalis angulata* and *Vernonia cinerea*. In a summary of research on groundnut at Coebiti in the period December 1973 – April 1974, Van Muijlwijk (1974c) further mentioned as weeds *Alternanthera sessilis*, *Portulaca oleracea* and *Torulinium ferax*. Bink (1975) reported on weeds in a 1974 experiment; in addition to the weeds mentioned above he found *Amaranthus dubius*, *Cyperus* sp., *Eleusine indica*, *Emilia sonchifolia*, *Euphorbia hirta*, *E. hypericifolia* (probably *E. hyssopifolia*), *Oldenlandia corymbosa* and *Paspalum conjugatum*.

The above data illustrate that even at the end of the first two years of cultivation of annual crops, a sizeable number of weed species known from other agricultural areas in Suriname (Dirven, 1968; Dumas & Ausan, 1978a; Segeren et al., 1984) was already present in the Coebiti fields. More species may have been present but gone unnoticed or unmentioned. The immediate planting and establishment of kudzu (*Pueraria phaseoloides*) probably hampered the spread of weeds after clearing, but once cultivation started their occurrence probably increased rapidly.

In later years other reports appeared in which weed species occurring in field trials were mentioned (Muileboom-Muffels, 1975; Van de Weg, 1975; Van de Wall, 1975; Bink, 1976; Van der Sar & Vermaat, 1978), and the weed flora at Coebiti was also surveyed (Van Grootveld, 1979; Kloos, 1980; Segeren et al., 1984).

6.8.1.2 Kabo

Before clearing, the vegetation of the Kabo area was surveyed (Section 4.1). Only a few herbaceous plants were encountered. No species known as weeds were found. To establish the presence of weed seeds in the soil, a number of samples of litter plus topsoil were taken and laid out for germination and identification of seedlings. Only one genus, *Cecropia* (Moraceae), a well known tree species of secondary forest growth, could be identified with certainty.

One of the first species at Kabo after clearing was *Digitaria horizontalis*. In 1979, Van Grootveld mentioned the grasses *Digitaria horizontalis*, *Echinochloa colonum* and *Eleusine indica* and the sedge *Fimbristylis littoralis* (cited as *F. miliacea*) as species of spotwise occurrence all over Kabo before soil preparation for the cultivation of crops had started. Furthermore, under the same conditions he recorded solitary plants (often only one specimen in Kabo) of *Amaranthus dubius*, *Borreria laevis*, *Conyza canadensis*, *Isotoma longiflora* (cited as *Laurentia longiflora*), *Ludwigia erecta* (cited as *Jussieua erecta*) and *Oldenlandia corym-*

bosa. Of these six species *C. canadensis* and *I. longiflora* have never since been found at Kabo, and these names are suspected to represent misidentified specimens of *Conyza bonariensis* and *Erechtites hieracifolia*, respectively, whereas archive material at CELOS makes it likely that *B. laevis* was actually *Borreria latifolia*. A few months later Van Grootveld (1979) observed hardly any change, except for an increased number of sedges, now also including *Cyperus rotundus*. Like at Coebiti, herbaceous wasteland plants and weeds seem to have established quickly, because in 1980, two years after clearing started, Kloos (1980) reported about 46 such species for Kabo.

These results show that somehow many weed and wasteland plant species arrived and established, once this site was subjected to clearing and agricultural practices.

6.8.2 Weed invasion

Table 61 presents some selected weeds of the Coastal Plain which have also been found at Coebiti and Kabo.

None of the species mentioned have their natural habitat in the rainforest. Some may have come from ruderal sites or shifting cultivation plots in the Zan-

Table 61. Some crop weeds known from the coastal plain of Suriname that are also found at Coebiti and Kabo (Dirven, 1968; Dumas & Ausan, 1978a; Kloos, 1980).

AMARANTHACEAE	GRAMINEAE
Alternanthera sessillis (L.) R.Br.	*Cenchrus echinatus* L.
Amaranthus dubius Mart.	*Cynodon dactylon* (L.) Pers.
	Digitaria horizontalis Willd.
COMPOSITAE	*Eleusine indica* (L.) Gaertn.
Eclipta prostata (L.) L.	*Echinochloa colonum* (L.) Link
(*Eclipta alba* (L.) Hassk.)	
Emilia sonchifolia (L.) DC.	ONAGRACEAE
Vernonia cinerea (L.) Less.	*Ludwigia hyssopifolia* (G. Don) Excll
	(*Jussieua linifolia* Vahl)
CYPERACEAE	*Ludwigia octovalvis* (Jacq) Raven
Cyperus luzulae Retz.	(*Jussieua suffruticosa* L.)
Cyperus rotundus L.	
Mariscus ligularis Urb.	PORTULACACEAE
(*Cyperus ligularis* L.)	*Portulaca oleracea* L.
Torulinium ferax Urb.	
(*Cyperus ferax* L.C. Rich.)	RUBIACEAE
	Borreria latifolia (Aubl.) Schum.
EUPHORBIACEAE	
Croton hirtus L'Herit.	SCROPHULARIACEAE
Croton trinitatis Millsp.	*Lindernia crustacea* (L.) F.v.M.
(*Croton miquelianus* L.)	*Scoparia dulcis* L.
Euphorbia heterophylla L.	
Euphorbia hirta L.	SOLANACEAE
Phyllanthus amarus Schumach. et Thonn.	*Physalis angulata* L.
Phyllanthus urinaria L.	

derij belt itself, but it is more likely that the majority came from outside the Zanderij area. Dispersal of seeds by birds, wind or migration along the roadsides may have been a possibility for some species, but given the distances involved, cannot have contributed much.

The majority of species most probably arrived as seeds or plant fragments adhering to equipment, footwear or clothes. Seeds or plant parts may also have been brought in with impure crop seeds, used jute bags or planting material. Agricultural machinery that had been used in the experimental fields of CELOS, near Paramaribo, was frequently transported to Coebiti, and weed and wasteland species may have come along. For the mulch tillage experiment (Section 6.3.2), mulch material harvested from CELOS fields was carried to Coebiti. Later, regular traffic and exchange of equipment between Coebiti and Kabo probably contributed to the rapid build-up of the weed and wasteland flora at Kabo.

Sanitary measures such as the use of clean crop seeds, clean planting material and prevention of dispersal through adherence to people or objects are necessary to prevent the further spread of weeds, especially of noxious species such as *Cyperus rotundus*.

Factors such as soil type, soil fertility and herbicide use, which may influence the occurrence of weeds and wasteland plants in the field and at ruderal sites, have been dealt with briefly by Van Grootveld (1979) and Kloos (1980), while Van der Sar (1976) mentioned effects of soil tillage on weed growth.

6.8.3 Weed control

6.8.3.1 Research

Weed control experiments were carried out at Coebiti only. Bink (1975) studied the effects of leaf spot (*Cercospora* spp.) control, fertilizer application and removing weeds from plant rows on the yield of groundnut. *Cercospora* control and fertilizers significantly increased yields, but weeding had no effect on yield. In fields where *Cercospora* was controlled, however, weed dry weight was about one-third of that on fields without *Cercospora* control; this was attributed primarily to the better closed crop canopy. Fertilizers did not affect the amount of weeds. Removal of weeds from plant rows 34 days after planting reduced the amount of weeds at harvest time by 50 per cent. *Cercospora* control, fertilization, and weeding together reduced weed growth to one-sixth of that of the non-treated plots. The results of this trial indicated the importance of a healthy crop to compete with weeds.

In 1975, pre-emergence application of three different herbicides with or without hilling was studied for effects on yield and weed growth (Muileboom-Muffels, 1975). The herbicides were prometryne (rate of a.i.: 1.25 kg ha^{-1}), diphenamid (5.60 kg ha^{-1}) and paraquat (0.5 per cent Gramoxone solution), the latter with one additional hand-weeding. A slightly beneficial effect of prometryne in combination with hilling was found, but no other significant yield differences. Hilling significantly reduced weed growth between but not in the rows.

Van der Sar (1976) noticed that weed growth was poorest on ploughed plots and strongest on minimum-tillage plots and intermediate in rotavated plots.

Weeding in maize, sorghum, soybean and groundnut significantly increased yields in two experiments (Van der Sar & Vermaat, 1978). The early maturing crop mungbean did not show clear effects of weeding on yields, whereas cowpea, another crop of comparatively short duration, benefited most when weeding was carried out only once (a second weeding resulted in lower yields because of damage to the crop). Because of a more closed canopy leguminous crops were generally more competitive with weeds than maize and sorghum.

As mechanical weed control, sometimes in combination with the use of paraquat, became more and more ineffective to control weed growth, the possible use of other herbicides was studied. In one study atrazine at a rate of a.i. of 2.8 kg ha^{-1} proved safe to use in maize, whether applied four days before planting, with or without soil incorporation, or pre-emergence. When applied at the same rate and in the same ways in sorghum, however, this herbicide adversely affected emergence, irrespective of how it was applied, and it depressed yield of the crop when applied before planting without soil incorporation. Leguminous crops sown at the observation site after harvest showed no signs of damage from atrazine residues.

Another trial was carried out, in which pre-emergence applications of atrazine at rates of a.i. of 0.4, 0.8, 1.2 and 1.6 kg ha^{-1} were compared with no weeding and hand-weeding up to nine weeks after planting. Hand-weeding up to nine weeks resulted in highest yields. No adverse effects were observed on emergence or on crop development, but weed growth was insuffciently controlled at any pre-emergence concentration of atrazine. From a third study, in which pre-emergence applications of atrazine, with or without additional hand-weeding were compared with post-emergence applications it was concluded that atrazine in sorghum could probably best be applied post-emergence at a rate of a.i. of 1 kg ha^{-1}, about one week after sowing. No conclusion could be drawn about the optimum rate.

Alachlor at a rate of a.i. of 2.16 kg ha^{-1}, either applied pre-planting, with or without soil incorporation, or pre-emergence, did not produce visible signs of damage to groundnut, soybean, cassava and mungbean. When applied pre-emergence in cowpea it caused initial growth retardation, not resulting in yield loss. Weed growth in this trial was low and seemed to be controlled satisfactorily however the alachlor was applied.

In the trials on no tillage or minimum tillage (Section 6.3.2) in maize, comparing direct sowing (no tillage), and sowing in 0.10 m wide, 0.06 m deep rotavated strips (minimum tillage), the tillage system had no effect on weed density six weeks after sowing, but weed weight at harvest was higher with direct sowing. The method of sowing did not affect plant population or yield. In this study the pre-emergence application of herbicide mixtures of atrazine, simazine and paraquat, and of atrazine, alachlor and glyphosate, gave lower weed weights at harvest and higher maize yields than mixtures of atrazine and paraquat, and of atrazine, alachlor and paraquat.

In the last years of the project, research was initiated on the critical period for weed control, and on the ecology of the weeds in relation to the agricultural practices. The outcomes of this work leading to a better understanding of crop–weed relationships and indicating weed control methods other than by chemicals are presented elsewhere (Everaarts, 1990).

6.8.3.2 Control practices

In the early experiments at Coebiti the weed control was mainly hand-weeding with either a hoe or a Dutch hoe. Mechanical hoeing and rotavating and hilling in groundnut were also tried. Sometimes herbicides – mainly paraquat – were used.

Gradually the emphasis shifted wholly to chemical weed control, consisting of post-planting spraying of alachlor at a rate of a.i. of 2.4 kg ha^{-1} in cassava and pre-emergence application of alachlor at the same rate in groundnut, soybean, cowpea, mungbean and maize. When maize was cultivated after groundnut, the application of alachlor was followed by an application of atrazine (2.5 kg ha^{-1}), 10 to 14 days after emergence, primarily to control volunteer groundnut. Weeds in sorghum were controlled by application of atrazine (2.5 kg ha^{-1}), 10 to 14 days after emergence. Paraquat (0.4 kg ha^{-1}) as a pre-emergence application was used in combination with the herbicides mentioned when no-tillage or minimum tillage plots were sprayed. A spray volume of 400 l water per ha was recommended.

Except for some Euphorbiaceous weeds, overall weed control with these herbicide regimes was generally satisfactory. Nevertheless, under certain conditions, such as excessive rainfall immediately after application, the effectiveness of the herbicides was reduced, sometimes necessitating supplementary hand-weeding. Mowing and disc-harrowing of the fallow vegetation remained essential, to reduce the regrowth of weeds, especially where grasses or creeping-rooting weeds dominated. Weeds like *Cyperus rotundus* continued to pose problems. The rates and types of herbicides recommended were only partly based on local studies. The same control could possibly be achieved by using lower dosages of the same or other herbicides, either singly or in combination, with a different timing of application.

7 Crops

Most research at Coebiti and Kabo focused on the food crops maize, sorghum, soybean, groundnut, cowpea, mungbean and cassava. Cassava, maize and groundnut are known from shifting cultivator plots in the Zanderij area; soybean, cowpea and mungbean are grown to a limited extent in the coastal area, whereas sorghum was included as a possible alternative cereal for seasons with less reliable rainfall. Other food crops that were studied incidentally include sweet potato and pigeon pea.

With a view to developing management technology for the Zanderij soils, mulch and green manure crops were also studied. At the end of the project grasses and forage legumes were included in the research programme: for the results, which are not included in this report, the reader is referred to Brandon-Van Steyn & Simons (1983).

The seven main crops will be discussed below individually in terms of varietal selection, yields, planting date, density and spacing, and production potential. Unless specified otherwise, standard cultivation practices were followed. These depended on knowledge available at the time. They might differ from the practices recommended in the sections on production potential, which take into account all that was learnt during the project and are based on the assumption that the fertility of the soil is in a steady state. The latter implies the following characteristics: pH(H_2O) about 5.5, P-Bray-I 15 mg kg^{-1}, exch. K 0.7 mmol kg^{-1}, ionic equivalents of exch. Mg 2.0 mmol kg^{-1}.

7.1 Cereals

7.1.1 Maize (Zea mays)

7.1.1.1 Varietal selection

The locally grown land varieties are relatively tall, very heterogeneous and have a low production capacity. Average grain yields are about 1200 kg ha^{-1}. Breeding work carried out in the 1960s led to the selection of six varieties (Van Marrewijk, 1979). CS1, CS2 and CS3, selected under coastal conditions, were derived from a local land variety. The synthetic varieties SR1, SR2 and SR3, composed of imported and locally developed inbred lines selected under both coastal and Coebiti conditions, were an improvement over the land variety. In comparative yield trials with Pioneer hybrids, the local selections yielded almost as much as the hybrids, but the plants were taller, bearing on average somewhat more (but smaller) ears higher on their stems. At Coebiti the local selections and the tropical hybrids yielded consistently less than in the coastal area. This can be ascribed to the low pH, the low nutrient availability and the easily occurring moisture stress in the sandy loam soils at Coebiti. The search for better adapted maize varieties was therefore continued. In the period 1978-80 several open-pollinated varieties were introduced, most of them from CIMMYT, Mexico (Appendix 5). The low fertility and high acidity of the soils concerned was stressed in the requests for this material. Though CIMMYT's breeding programme does not specifically cover this particular problem, their international network of trials does enable them to indicate varieties that may be adapted to such conditions.

The material was compared in a number of yield trials, some of them including one of the local selections. All varieties matured in about 15 weeks, tasselling taking place about 8 weeks after planting. Virtually all introductions outyielded the local selections. The overall yield level was about 4 t ha^{-1} (Table 62). There were no great differences in yield between varieties or between trials, suggesting that there is an overriding factor limiting maize yields on the Zanderij soils. Some introductions were consistently ranked among the best yielders but no single variety appeared particularly adapted. Trials with the same CIMMYT varieties carried out in the coastal area gave yields that on average were more than 50 per cent higher than those obtained at Coebiti (Lata, 1979), again indicating a soil-related rather than a climate-related constraint. Therefore, it can hardly be expected that the yield level of maize in the Zanderij area can be raised through the use of other genotypes.

7.1.1.2 Yields

The grain yields obtained in the many field trials carried out at Coebiti and Kabo since 1972 ranged from 0.02 to 5.40 t ha^{-1} with an average of 2.78 t ha^{-1}. Fig. 54 refers to the same trials as Curve C in Fig 20, but in Fig. 54 the data

Table 62. Maize. Yields (t ha^{-1}) of the best four entries in six comparative yield trials (1972-1981).

Entry	Yield	Entry	Yield
X352	3.37	Amarillo Dentado	5.00
X105A	3.31	Mezcla Tropical Blanca	4.54
X304A	3.18	Tuxpeño Caribe 1	4.40
X304B	3.18	Mezcla Amarilla	4.29
Cotaxtla 7429	3.93	Across 7728	4.39
CMS 14	3.81	Sete Lagoas 7728	4.39
Poza Rica 7528	3.66	Ludhiana 7528	4.39
CMS 04	3.63	CMS 04	4.28
Across 7726	4.42	Across 7728	4.77
Pool 26	4.26	Sete Lagoas	4.56
CMS 04	4.17	CMS 04	4.45
La Maquina 7827	4.14	Across 7726	4.19

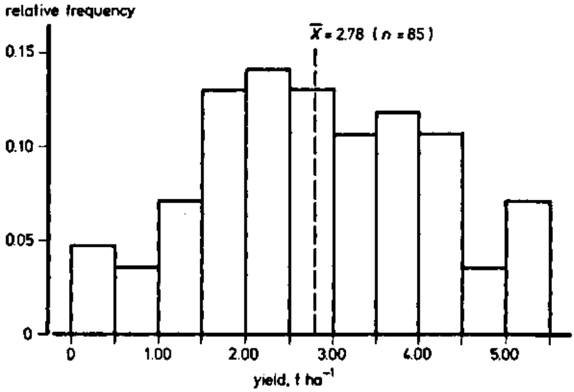


Fig. 54. Frequency distribution of experimental maize yields under current cultural practices. 1972-1982.

have not been ordered according to planting time. The variety trials are represented by the average of the best four entries. For the other field trials only the yield for the treatment representing current cultural practices (Section 6.1.2) was included; the yields obtained with low or high fertilizer levels, irrigation, or soil tillage other than ploughing have been excluded. A production level above 4 t ha^{-1} was obtained in about 22 per cent of the trials; only six times did the yield exceed 5 t ha^{-1}. As shown in Section 6.1, some of the low yields can be explained by an unfavourable rainfall distribution during the growing season. The average yield for maize grown during the long rainy season was 3.37 t ha^{-1} (n = 38), as against 2.41 t ha^{-1} (n = 47) for the remainder of the year. But even in the long rainy season yields as low as 1.17 t ha^{-1} have been recorded, indicating limitations other than drought stress.

In Section 6.6.2 it was shown that much higher yields, up to 6.5 t ha^{-1}, can be obtained when maize is planted in April and fertilizer nitrogen is split-applied, at a total rate of 250 kg ha^{-1}.

7.1.1.3 Plant density and spacing

In the earlier trials, maize was planted at 90 x 30 cm or about 37 000 plants ha^{-1}. With the introduction of CIMMYT varieties, row distance was reduced to 75 cm and plant distance in the row to 25 or 20 cm, corresponding with densities of about 53 000 or 66 000 plants ha^{-1}, respectively.

The effects of plant density on yield and yield components were studied with the CIMMYT variety Cotaxtla at Coebiti in the planting-date experiment discussed in Section 6.1. The trial was of a systematic design based on an arrangement of plants in squares.

Grain yields per hectare increased with density when moisture was not limiting, but with an inadequate moisture supply the yields decreased with increasing

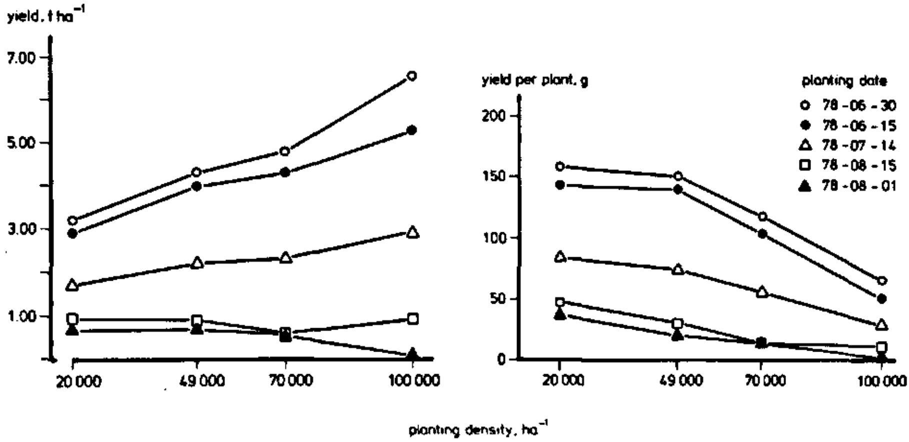


Fig. 55. Maize yields per ha (left) and maize yields per plant (right) in relation to plant density and planting date. Coebiti.

density (Fig. 55, left). Yields per plant decreased with increasing density, irrespective of the planting date (Fig. 55, right). The higher densities were accompanied by a higher percentage of lodged plants.

The differences in yield per plant were mainly the result of differences in ear size, though the mean number of ears per plant also decreased with increasing density (Table 63A). Only at very low densities did this number exceed one; at normal densities there were always barren plants.

In a second density experiment at Coebiti using a randomized block design, grain yield varied little with density, but ear weight, number of ears per plant and 1000-grain mass decreased, whereas lodging increased with increasing density (Table 63B). The trial was carried out during the long rainy season – there were no periods with drought stress. The percentage lodging was exceptionally high because of the unusually strong winds accompanying heavy rainfall shortly before harvesting. The lodged plants were included in the harvest; with combine harvesting most of them would have been lost (cf. Section 8.3.2.1).

In conclusion, at row distances of 75 cm there is little justification in using plant distances of less than 25 cm in the row.

7.1.1.4 Production potential

Around 1980 maize production in Suriname was limited to 183 ha (Table 1). Maize is mainly grown as a catch crop on recently cleared land and on shifting cultivator plots. In the coastal area it is grown in backyards or as a second crop after rice. Most maize is consumed as a vegetable. Little is grown for the dry grain, notwithstanding the substantial annual imports of maize for animal feed,

Table 63. A. Maize cv. Cotaxtla. Number of ears per 100 plants as affected by plant density and planting date. B. Maize cv. CMS 04. Yield and yield characteristics as affected by plant density.

A	Plants per ha			
Planting date (1978)	20 000	49 000	70 000	100 000
15 June	115	97	92	80
30 June	121	103	95	94
14 July	117	97	91	83
1 August	58	22	12	9
15 August	99	68	72	78
B	**Plants per ha**			
Characteristic	42 300	50 000	59 500	76 200
yield, t ha^{-1}	4.80	5.01	5.08	4.94
ear mass, g	120	108	93	81
ears per 100 plants	96	94	91	81
1000-grain mass, g	321	312	302	293
lodged plants, per cent	25	23	32	35

which in 1979 amounted to 32 000 tonnes (Anon., 1981).

The main limitations to maize production in the Zanderij area are related to climatic, nutritional, disease and insect stress. The relatively short days and the high night temperatures reduce the amount of carbohydrates available for grain filling. This is accentuated by a rapid dying of the leaves after silking, resulting in a quick decline of the leaf area index. The often poor root distribution because of subsoil acidity and compaction easily leads to moisture stress and to lodging in the case of tall cultivars. Moisture stress can best be avoided by planting in April.

Table 64 summarizes the recommended cultural practices. They were derived from this section and from the various subsections of Section 6. The recommended fertilizer rates hold only if the soil has the abovementioned values: 15 mg kg^{-1} for P-Bray-I, 0.7 mmol kg^{-1} for exchangeable K and 2.0 mmol kg^{-1} (ionic equivalents) for exchangeable Mg. It is assumed that with the chosen combination of target yield and fertilizer applications the values of the soil fertility indices do not change, so that there is a steady-state situation as far as soil fertility is concerned. Yields higher than 4.5 tonnes might be obtained under favourable moisture conditions (Section 6.6.2), but relatively high fertilizer application rates are required for such an additional yield.

7.1.2 Sorghum (Sorghum bicolor)

7.1.2.1 Cultural practices

In the experimental work the US cultivar Martin obtained from the Suriname

Table 64. Recommended cultural practices for maize growing. Target grain yield is 4.5 t ha^{-1}.

Planting time	April
Plant density, ha^{-1}	50 000; 18 kg seed
Cultivars	from CIMMYT
Soil tillage	ploughing 25 cm, and harrowing
Crop protection measures	not renumerative, but if necessary one application of monocrotophos; 0.5 l per ha
Weed control	pre-emergence alachlor; 2.4 kg a.i. per ha post-emergence atrazine, 2.5 kg a.i. per ha[a])
Optimum pH (H_2O)[b])	5.0-5.6
Fertilizer rates[c]), kg ha^{-1}	
N	2 × 85; at planting and 4 weeks later
P	40, at planting
K	2 × 50, at planting and 4 weeks later
Mg	30, at planting

[a]) Only if maize is cultivated after groundnut.
[b]) To maintain this pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.
[c]) Per tonne of extra yield above 4.5 t ha^{-1}, additional rates of fertilizer nutrients are: 50, 20, 40, 50 kg ha^{-1} of N, P, K and Mg, respectively.

Agricultural Experiment Station, and the cultivar IS 2745, originating from ICRISAT, India, were used. It is not known whether they are Al-tolerant. Both cultivars are of the semi-dwarf type and have a growing cycle of about 100 days. Tall cultivars were not considered, as they are unsuitable for mechanized harvesting.

In all experiments sorghum was planted in rows 50 cm apart. When hand-sown the seeds were put in hills 15 cm apart, 3 seeds per hill, followed by thinning to one plant per hill 10 to 14 days after emergence. With mechanized sowing, the planter was adjusted to 10 cm in the row which – depending on the percentage of emergence – normally resulted in plant distances of between 15 and 12 cm, corresponding to about 133 000 – 167 000 plants ha^{-1}. No density or spacing experiments were conducted.

7.1.2.2 Yields and planting date

The yields recorded in the period 1972-82 in the various experiments are presented in Fig. 56. This comprises all yields obtained with the current cultural practices, irrespective of planting date or cultivar used. The yields ranged from 0.28 to 4.19 t ha^{-1}, with an average of 1.99 t ha^{-1}. In 34 per cent of the cases yields were higher than 2.5 t ha^{-1}, and in over 40 per cent they were less than 1.5 t ha^{-1}. Yields above 3 t ha^{-1} were recorded four times.

Many of these low yields were explained by soil moisture shortage; others were ascribed to thin stands or unfavourable weather at the time of harvesting. Sorghum was mostly planted either in the second half of the long rainy season or at the beginning of the short rainy season so that the crop ripened during a dry period. The long rainy season is considered unsuitable, because of too

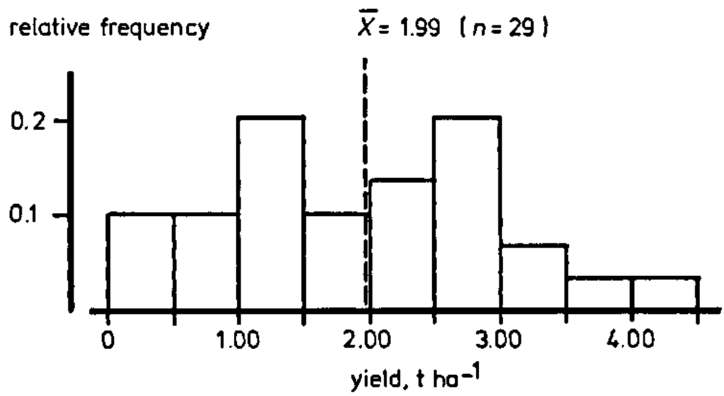


Fig. 56. Frequency distribution of experimental sorghum yields under current cultural practices. 1972-1982.

great a risk of unfavourable weather when the grain matures. Ripening sorghum is extremely susceptible to grain moulds, which can cause complete crop failures (Section 6.7.2.1). As shown in Fig. 21 (Section 6.1.2), plantings in the period October-December gave highest yields. Generally, rainfall is evenly distributed then and weather is dry during ripening. Planting in July, i.e. in the second half of the long rainy season, often meets with prolonged dry spells that coincide with anthesis when sorghum is most sensitive to water shortages.

As there are no data from systematic experiments on planting date and the data from the various plantings made throughout the years are rather few and poorly distributed it is impossible to draw firm conclusions on production as affected by planting date and growing season.

7.1.2.3 Production potential

In Suriname sorghum is not grown by local farmers. The crop was included in the project to have a second cereal apart from maize, and because of its drought tolerance. The latter was thought to be an important characteristic in view of the erratic rainfall outside the long rainy season, and the low water-holding capacity of the soils concerned. As to its utilization, sorghum grain could at least partly replace maize in animal feed mixtures.

The most important factors limiting sorghum production on the Zanderij soils are related to climatic and disease stress. The humid climate is conducive to fungal leaf diseases that result in leaf loss and incomplete grain filling. The young grains are readily attacked by various fungi under cloudy humid conditions during grain filling and ripening stages. The low water-holding capacity of the soils and the shallow rooting quickly lead to drought stress, if sorghum is grown in a season with erratic rainfall. Generally there is little trouble from insect pests. In small plots bird damage can be relatively serious but since there are no typical

Table 65. Recommended cultural practices for sorghum growing. Target grain yield is 3.5 t ha^{-1}.

Planting time	November
Plant density, ha^{-1}	150 000; 5 kg seed
Cultivars	semi-dwarf types
Soil tillage	ploughing 25 cm, and harrowing
Crop protection measures	avoid humid conditions during ripening
Weed control	pre-emergence alachlor; 2.4 kg a.i. per ha
Optimum pH (H_2O)[a])	5.0-5.6
Fertilizer rates, kg ha^{-1}	
N	2 × 70; at planting and 4 weeks later
P	20, at planting
K	2 × 40, at planting and 4 weeks later
Mg	0

[a]) To maintain the indicated pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.

migratory birds in Suriname, bird damage is not expected to become a problem when sorghum is grown on a large scale.

Table 65 summarizes the recommended cultural practices, as derived from this and other sections. The target yield and fertilizer rates mentioned refer to steady-state conditions as far as soil fertility is concerned. If no experimental data for sorghum were available, the recommendations were formulated by comparing the situation with maize. Although higher yields might be obtained with higher fertilizer rates, such extra inputs are not recommended because of the high risk of crop losses.

7.2 Legumes

7.2.1 Soybean (Glycine max)

7.2.1.1 Varietal selection

The traditional soybean cultivars of the coastal area are Laris and Vada, both introduced from Java in the late 1940s. Laris branches profusely, tends to lodge if vegetative growth is stimulated, and shatters its seeds upon maturity. Vada does not have these disadvantages, but when the crop matures during a rainy period its white seeds appear to be more sensitive to fungal attacks and staining than the small black seeds of Laris. This may explain the popularity of Laris.

The first cultivar introduced for the Zanderij soils, Jupiter, has been developed specially for the tropics and performed well in comparative yield experiments on the infertile, acid soils of the Intermediate Savannas of Guyana (Hinson, 1972). Initial results on the Zanderij soils were disappointing. In a non-replicated observation plot planted during the short rainy season (1972) it yielded 0.53

compared with up to 1.20 t ha^{-1} for Vada under comparable conditions. From 1977 onwards cultivars and lines were received from the International Institute of Tropical Agriculture (IITA), Nigeria, the Asian Vegetable Research and Development Centre (AVRDC), Taiwan, the International Soybean Program (INTSOY) of the University of Illinois, USA, and from the Instituto Nacional de Pesquisas de Amazonia (INPA), Brazil (Appendix 5).

A main problem was the sensitivity to daylength. The AVRDC lines and many of the other introductions proved to be not adapted to the prevailing short days. Plants flowered early, remained small and produced few seeds. The short plants invariably formed terminal inflorescences at an early growth stage, thus making further stem elongation impossible. Only a few introductions attained a plant height similar to that of the local cultivars Laris and Vada.

A number of comparative yield trials were carried out with the plant material from INTSOY and IITA (Table 66). Yield and plant height varied from experiment to experiment; this may reflect the seasonal variations in daylength and moisture conditions. Some of these trials were planted in the short rainy season, others in the second half of the long rainy season. Based on the results obtained, SJ-2, UFV-1 (BP-2), ICA L-215, Jupiter and Vada were selected for further testing. Jupiter was used in almost all the experiments with soybean.

Variability in Jupiter entry no. 77018 offered the possibility of selecting a number of progenies differing in height from the original plant type. In soybean, plant height often positively correlates with yield, so that taller plants could mean a higher production potential. Comparisons during three successive seasons (Table 67) showed that on average the selections yielded more than the original cultivar. The differences were more pronounced in the short rainy season than in the second half of the long rainy season. The days being shortest

Table 66. Soybean. Yields (t ha^{-1}) and plant height (cm) of the best four entries in five comparative yield trials (1977-1981). From Fung Kon Sang & Wienk (1981).

Entry	Yield	Height	Entry	Yield	Height
Jupiter	2.48	67	Bossier	1.90	50
Laris	1.93	84	TGm 294-4-2371	1.80	50
TGm 210-1-2363	1.74	37	TGm 260-2-2-4292	1.53	44
TGm 210-1-2205	1.69	44	TGm 249-3	1.30	36
SJ-2	1.22	50	ICA L-215	2.58	76
Impr. Pelican	1.18	47	Vada	2.41	85
UFV-1 (BP-2)	1.11	53	SJ-2	2.37	53
Jupiter	0.81	37	IGH-24	2.32	53
SJ-2	1.72	71			
UFV-1 (BP-2)	1.72	79			
IGH-24	1.65	80			
Vada	1.51	97			

Table 67. Soybean. Yields (t ha^{-1}) of ten lines selected from the cv. Jupiter (Entry no. 77018) compared with the original population during three successive seasons.

Entry	Seasons[a])			Mean yield	
	1	2	3	t ha^{-1}	%
77018-12	3.70	1.59	2.60	2.63	175
-25	2.00	1.76	3.44	2.40	160
-21	2.45	1.61	2.73	2.26	151
-49	2.08	1.77	2.76	2.20	147
-2	–	1.65	2.67	2.16	144
-28	2.30	1.31	2.62	2.08	139
-57	2.20	1.32	2.65	2.05	137
-61	1.88	1.21	2.86	1.98	132
-64	1.57	1.31	2.10	1.66	111
-37	1.66	0.79	2.07	1.50	100
77018	1.39	1.23	1.87	1.50	100

[a]) 1 = Dec. 1980–March 1981; 2 = June–Sept. 1981;
3 = Dec. 1981–March 1982.

in December, this difference cannot be ascribed to daylength, and must be the result of unfavourable moisture conditions in the second sowing. Further evaluation of the best lines is required before any definite selection can be made.

7.2.1.2 Yields

Experimental yields ranged from 0.34 to 4.01 t ha^{-1}, with an average (n = 40) of 1.71 t ha^{-1} (Fig. 57). Again, only the yields obtained with the standard methods have been included; from the variety trials only the highest yield was included.

The yields rarely exceeded 3 t ha^{-1}; in more than 55 per cent of the cases the yield was below 2 t ha^{-1}, whereas one-third of the yields were between 2.0 and 2.5 t ha^{-1}.

The yields obtained leave sufficient room for improvement. On the other hand they compare favourably with experimental yields obtained in the period 1949-59 in the coastal area (Ter Horst, 1961). In Section 6.1.2 and Fig. 21 it was shown that soybean yielded best when sown in April-May or in October-December, indicating that moisture stress is a severe cause of low yields. For more details the reader is referred to Sections 6.2.2 and 6.6.1.

7.2.1.3 Plant density and spacing

Soybean was planted in rows 50 cm apart, and a plant spacing of 15 cm was aimed at in the row. When hand-sown, the hills were spaced 10-15 cm apart, 3 seeds per hill. About 2 weeks after emergence the stand was thinned to one plant per hill thus resulting in a plant density of about 133 000 plants per hectare. With mechanized sowing, the planter was adjusted to 6 cm in the row, the short-

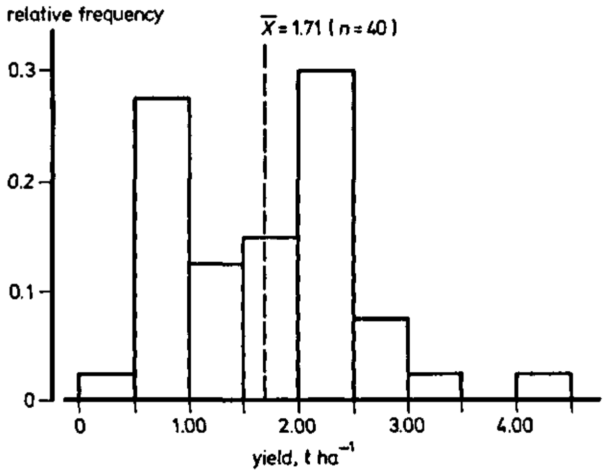


Fig. 57. Frequency distribution of experimental soybean yields under current cultural practices. 1972-1982.

est distance possible. Emergence percentage of soybean seed generally being very low, this resulted in plant distances between 15 and 12 cm, corresponding with 133 000 – 167 000 plants ha^{-1}.

Increasing plant distance in the row from 10 to 20 cm had no statistically significant (P = 0.05) effect on yield but the number of pods per plant increased, whereas plant height showed the opposite response (Table 68). The taller Vada responded more strongly than the shorter Jupiter.

Table 68. Soybean. Performance of the cvs Jupiter and Vada as affected by plant distance in rows 50 cm apart.

Cultivar and crop parameters	Planting date[a])	Plant distance, cm		
		10	15	20
Jupiter				
yield, t ha^{-1}	1	2.17	2.18	2.30
	2	1.66	1.38	1.52
plant height, cm	1	62	56	55
	2	49	48	49
pods per plant	1	36	48	61
	2	37	57	59
Vada				
yield, t ha^{-1}	1	1.30	1.17	1.60
	2	1.15	1.02	1.08
plant height, cm	1	130	120	107
	2	94	95	85
pods per plant	1	50	65	100
	2	34	55	70

[a]) 1 = Dec. 1981; 2 = June 1982.

7.2.1.4 Production potential

Soybean is grown in the coastal area, almost exclusively by small farmers of Javanese origin. In statistics on production the crop is classified together with cowpea and mungbean as 'other grain legumes', so no separate data are available on its area or production. In the period 1950-58 an average of approximately 75 ha was sown to soybean every year (Ter Horst, 1961). This area has probably since decreased. Soybean is grown for its dry seeds which are utilized for the preparation of various special food products such as bean sprouts, soya sauce, soya cheese and soya cake. The soybean products used in locally composed animal feed mixtures are imported, but no data are available on the quantities involved.

There are no serious diseases or pests that limit soybean production on the Zanderij soils. The most important production constraints are the low soil fertility, the often uneven moisture supply and the unreliable weather during the dry season. Soybean is very susceptible to drought during the pod-filling stage and requires more soil moisture for germination than most other crops. Excessive rainfall during ripening accompanied by little sunshine and high air humidity quickly leads to seed deterioration and sometimes even to germination in the pods, resulting in substantial yield losses. Black-seeded cultivars seem less susceptible than the white-seeded ones. The quality of soybean seed material is another important limiting factor. The seeds quickly lose their viability in storage. This is aggravated by adverse weather conditions during ripening.

Table 69 summarizes the recommended cultural practices, as derived from this and other sections. As with maize and sorghum, a steady state as regards soil fertility is aimed at. There is no clear experimental evidence that yields will substantially increase if fertilizer rates are higher than recommended.

Table 69. Recommended cultural practices for soybean growing. Target seed yield is 2.5 t ha^{-1}.

Planting time	April or November
Plant density, ha^{-1}	150 000; 40 kg seed
Cultivars	SJ-2, Jupiter, Vada, UFV-1 (BP-2) and ICA L-215
Inoculum, kg ha^{-1}	12; granular, specific; combined with planting
Soil tillage	ploughing 25 cm, and harrowing
Crop protection measures	seed treatment with thiram
Weed control	pre-emergence alachlor, 2.4 kg a.i. per ha
Optimum pH (H_2O)[a])	5.2-6.0
Fertilizer rates, kg ha^{-1}	
N	none
P	40, at planting
K	2 × 60, at planting and 4 weeks later
Mg	15, at planting

[a]) To maintain the indicated pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.

7.2.2 *Groundnut* (Arachis hypogaea)

7.2.2.1 *Varietal selection*

The local cultivars are of the Spanish type. Compared with other Spanish type cultivars, the recommended cultivar Matjan, introduced from Java in 1950, has large leaves and fairly large seeds. The cultivar is susceptible to leaf spot diseases and to leaf rust, both of which can cause considerable yield losses (Section 6.7.2.2). In the absence of diseases Matjan matures in about 110 days, and is therefore considered an early-maturing cultivar.

In the earliest experiments at Coebiti the cultivar Matjan performed well (Wienk, 1979), better than under coastal conditions, and better than the cultivar Altika which was developed for the acid, infertile soils of the Intermediate Savannas of Guyana (Norden et al., 1972).

A number of early-maturing groundnut lines of the upright plant type were screened for general performance under Coebiti conditions. The lines had been selected from an F_1 population introduced from Nigeria in 1979. On the basis of yield and resistance to leaf spot diseases three lines were selected for comparison with the cultivar Matjan. Leaf spot diseases were controlled by spraying regularly with Benlate (a.i. benomyl). Matjan suffered from rust much more than the selections, and because of the resulting premature leaf fall it was outyielded (Table 70). However, the pods of Matjan were cleaner than those of the selections and the seeds were not mottled as with the selections. Matjan controlled weeds better than the selections did.

Varietal comparisons with late-maturing cultivars at Coebiti were not made until 1981 when technology was available for an adequate control of leaf spot diseases and leaf rust. Until then such comparisons favoured the early-maturing cultivars. The build-up of pathogens in the early-maturing cultivars towards the end of their growing cycle nearly always led to premature harvesting of the late-maturing cultivars and thus to low production levels. In a comparative trial at Kabo, for instance, Matjan yielded 2.39 t ha^{-1} against 1.22 t ha^{-1} for Altika. No adequate control of leaf spot diseases and leaf rust was obtained in this experiment.

In the first variety trial with adequate disease control, the early cultivars Matjan and 69262-13 were compared with the late-maturing cultivars Florigiant and Altika. Their times of ripening were synchronized by planting Altika and Flori-

Table 70. Groundnut. Performance of three selections in comparison with cv. Matjan. From Bink (1976b).

Entry	Pod yield, t ha^{-1}	1000-seed mass, g	Shelling fraction
Matjan	2.90	600	0.78
69262-13	3.48	600	0.77
69262-29	3.68	600	0.78
69262-33	3.78	630	0.79

Table 71. Groundnut. Pod yields (t ha^{-1}) of late and early maturing cultivars, planted late in the long rainy season (Experiment 1) and early in the short rainy season (Experiment 2).

Experiment	Late maturing		Early maturing	
	cultivar	yield	cultivar	yield
1	Altika	3.16	69262-13	2.98
	Florigiant	3.15	Matjan	2.54
2	Florigiant	3.37	Matjan	4.14

giant four weeks ahead of Matjan and 69262-13. Furadan (a.i. carbofuran) was applied pre-planting and Bravo (a.i. chlorothalonil) was sprayed regularly to control insects, nematodes, leaf spot diseases and leaf rust. Altika and Florigiant produced most and Matjan least in this experiment (Table 71). An unusually early start of the long dry season affected the later planted cultivars more than the cultivars sown first. The comparison was not therefore completely reliable.

In a second experiment Florigiant and Matjan were compared in combination with different fungicide application methods. The cultivars were planted at the same date in the short rainy season. With adequate disease control and ample rainfall Matjan now outyielded Florigiant (Table 71).

So far Matjan has proved to be a good cultivar and there seems little reason to replace it by another early-maturing one unless this has a much better resistance to the prevailing leaf diseases. The search for adapted late-maturing cultivars should be continued. A longer growing cycle might offer the possibility of planting at the beginning of the long rainy season. This would mean fewer workability problems with soil preparation and planting (Section 8.2.2.3), and a better use of the long rainy season. A spreading plant type would furthermore facilitate mechanized harvesting.

7.2.2.2 Yields

The average groundnut yield in the coastal area is about 1 tonne of unshelled nuts per ha (Ahlawat & Samlal, 1979). The pod yields obtained with the cultivar Matjan in the various field trials since 1972 at Coebiti and Kabo varied from 0.68 to 5.04 t ha^{-1}; the average ($n = 56$) yield was 2.46 t ha^{-1} (Fig. 58). This includes all field trials with the standard methods irrespective of their planting date. In 25 per cent of the experiments yields exceeded 3 t ha^{-1}; yields lower than 1.5 t ha^{-1} were obtained in nearly 20 per cent of the experiments. The low yields can almost all be explained by drought, excessive weed growth or inadequate disease control. The high yield of 5 t ha^{-1} was obtained in an experiment planted in the second half of the long rainy season, with good insect, nematode and disease control, and adequate moisture supply. It shows that Matjan has a good production potential and is well adapted.

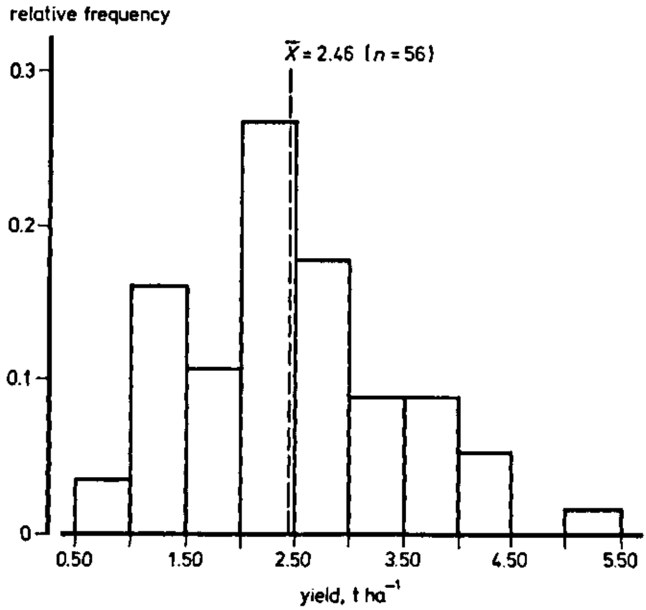


Fig. 58. Frequency distribution of experimental groundnut pod yields under current cultural practices. 1972-1982.

For a good quality product the planting of groundnut has to be timed such that the crop can be harvested in a reliable dry period. The best period for harvesting is the long dry season. With a growing cycle of 110 days, this would require planting late June – early July. Later planting increases the risk of moisture shortage and often it is not possible to sow earlier because of workability problems with soil preparation (Section 8.2.2.3).

The relationships between yields and planting date were discussed in Sections 6.1.2 and 6.1.3 and shown in Fig. 21 and Fig. 22. For the time being, it can be concluded that the highest yields are to be obtained from plantings between mid-May and the end of July, provided adequate crop protection measures are taken.

7.2.2.3 Plant density and spacing

The economically optimum plant density for the cultivar Matjan under coastal conditions was established at about 110 000 plants ha^{-1}, and a plant spacing of 30 x 30 cm was advised (Ter Horst, 1959). In the experiments at Coebiti a similar density was used but the spacing was altered to 60 x 15 cm, enabling agricultural machinery to enter the field.

Based on a density of 110 000 plants ha^{-1}, four plant arrangements were compared: 60 x 15 cm, 75 x 12 cm, 90 x 10 cm and the double-row arrangement 70 x (20 x 20) cm. The crop, sown in the second half of the long rainy season of 1973, suffered from leaf spot diseases, so that only moderate yields were obtained. The yield was highest for the 60 x 15 cm spacing. No explanation can be provided for this rather unexpected effect, though microclimatic differences affecting the incidence of leaf spot diseases cannot be ruled out.

The effect of plant density on yield was studied in two systematic experiments of the fan design. Ten densities based on a square arrangement of plants and ranging from 45 200 to 250 000 plants ha^{-1} were compared. The first experiment, planted in the short rainy season of 1973, was sprayed once, the second experiment, planted towards the end of the long rainy season of 1974, was sprayed every two weeks with Benlate (a.i. benomyl) against leaf spot diseases. The effect of plant density on yield was the same in both trials. Yield rapidly increased with density until about 120 000 plants ha^{-1}, whereas above 140 000 plants ha^{-1} there was hardly any yield increase (Fig. 59). An optimum of 120 000 to 140 000 plants ha^{-1} is rather low for Spanish type cultivars, which are normally planted at 160 000 to 180 000 plants ha^{-1}. This lower optimum spacing for the cultivar Matjan should probably be ascribed to its relatively large leaves, and its open growth habit which is characterized by long upright branches.

In the second experiment, the yield was about 20 per cent higher than in the first experiment; plant density appeared not to have affected this relative difference. The difference in yield was ascribed to a better leaf spot disease control, although a seasonal effect could not be completely excluded.

The above results were later translated into planting at 50 x 12 cm, which at 90 per cent emergence corresponds with 150 000 plants ha^{-1}. This higher density was chosen with a view to mechanized harvesting – the entangled plants

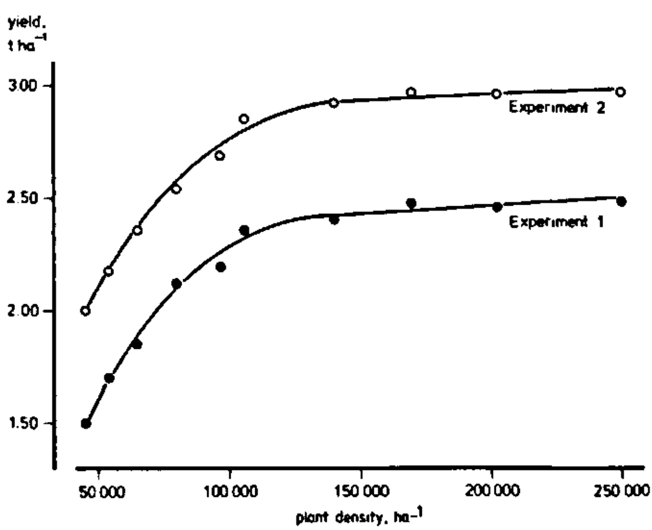


Fig. 59. Groundnut pod yields in relation to plant density. Experiment 1 after Van Muijlwijk (1974), Experiment 2 after Van de Wall (1975).

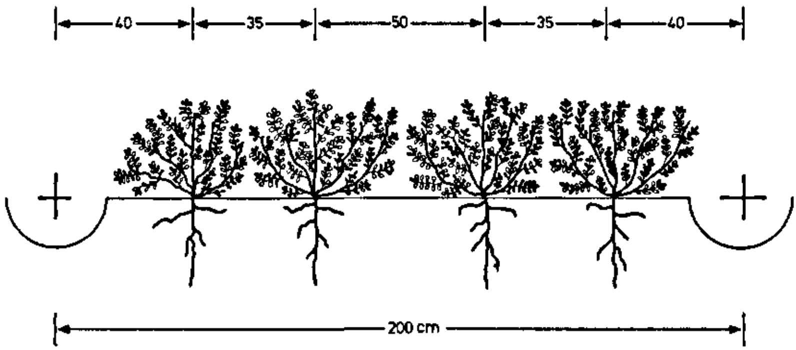


Fig. 60. Four-close-row planting system for groundnut based on wheel tracks 200 cm apart.

facilitate lifting and inverting. The row distance of 50 cm was based on a normalization of 25 cm.

In 1982 a groundnut harvester was introduced and this led to a controlled-traffic system and related planting pattern (Fig. 60). The groundnut is planted in rows on 2 m wide soil beds formed between tractor wheels. The spraying and harvesting equipment also uses the wheel tracks, thus confining soil compaction and reducing crop damage and harvesting losses. The soil area lost to the wheel tracks is compensated for by narrower row spacings.

7.2.2.4 Production potential

Groundnut is predominantly a crop of the sandy ridges in the coastal area. As the average farm size is small, there are no large production units. Though most soil preparation is mechanized, all harvesting is done by hand, making groundnut production economically unattractive. As a result the area under groundnut fell from about 600 ha in the early 1960s to a mere 200 ha in 1980. Most of the production is used in the manufacturing of peanut butter and special food products. Consumption exceeds production several times over, the differences being covered by imports, the value of which is estimated at about SRG 1 million annually.

The main factors limiting groundnut production are the leaf spot diseases and leaf rust. The diseases are virtually absent in recently cleared areas but build up rapidly once the soil has been cropped a few times with groundnut. If control measures are adequate, groundnut is a promising crop for the Zanderij area.

Table 72 summarizes the recommended cultural practices as derived from this and other sections. As with the other crops, a steady state of soil fertility is aimed at. Yields higher than the indicated 4 t ha^{-1} might be obtained. For each extra tonne of pod yield, additional applications should be 15, 30 and 30 kg ha^{-1} of P, K and Mg, respectively.

Table 72. Recommended cultural practices for groundnut growing. Target pod yield is 4 t ha^{-1}.

Planting time	June or December
Plant density, ha^{-1}	150 000, 50 × 12 cm; 100 kg seed
Cultivar	Matjan
Inoculum, kg ha^{-1}	12; granular, specific; combined with planting
Soil tillage	ploughing 25 cm, or rotavating 15 cm
Crop protection measures	five two-weekly applications of chlorothalonil (1.75 l ha^{-1}), starting 4 weeks after planting
Weed control	pre-emergence alachlor, 2.4 kg a.i. per ha
Optimum pH(H_2O)[a])	5.2-6.2
Fertilizer rates, kg ha^{-1}	
N	none
P	20, at planting
K	60, at planting
Mg	30, at planting

[a]) To maintain the indicated pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.

7.2.3 *Cowpea* (Vigna unguiculata)

7.2.3.1 *Varietal selection*

In Suriname only a few cultivars are known and used for human consumption. The two most important types have uniform brown, oval to ovoid or rhomboid seeds, and can be classified as crowders; they often occur mixed. The third type is a blackeye, and the fourth one a creampea type. With the exception of the creampea, they have a 100-seed mass of 16 to 17 g. The local creampea is nearly extinct. None of these cultivars is suitable for mechanized harvesting. They often have long trailing stems and ripen very unevenly with pods borne near the ground and mostly concealed by the foliage.

At Coebiti 'African Red' was one of the reference cultivars. It has an upright growth habit, a fairly even ripening, and pods well above the ground. The small reddish-brown seeds, however, differ too much from the traditional cultivars to be acceptable for human consumption.

The cultivars tested at Coebiti in 1973 and 1974 comprised material that had been introduced earlier by CELOS for the coastal area. From 1975 onwards only cultivars from IITA, Nigeria, were submitted to varietal tests (Appendix 5). The 1973 and 1974 experiments comprised cultivars with seeds that resembled the current local cultivars. No outstanding yielders were encountered (Table 73). Taking other characteristics into account too, no cultivars were selected to replace the local ones.

After 1975 the experiments were done on a cooperative basis with the International Institute for Tropical Agriculture (IITA), Nigeria, and included cultivars with seeds that often differed from the current local material. Usually the introductions did not produce much better than the standard cultivar (Table 74). On the other hand, many of the better yielding entries were superior to the local

Table 73. Cowpea. Seed yields (t ha^{-1}) of the best four entries and the reference cultivar in four comparative yield trials at Coebiti in 1973 and 1974.

Entry	Yield	Entry	Yield
Type: blackeye		Type: blackeye	
PI 165486	0.57	PI 293477	0.96
Acc. 73031	0.45	Acc. 73026	0.91
Acc. 593	0.45	PI 165486	0.84
Acc. 73030	0.34	PI 124609	0.78
reference (Blackeye)	0.47	reference (African Red)	0.95
Type: crowder		Type: creampea	
Acc. 73027	1.14	185 × 40-3/4-40 L.9	1.14
Acc. 6017	1.12	5/8-40-1/4-66-74, 1/8-50 L.4	1.07
Capucijner 5403A	1.02	PI 293497	0.97
Kwarra	0.90	Acc. 73021	0.95
reference (Capucijner 6101)	1.03	reference (African Red)	1.47

Table 74. Cowpea. Seed yields (t ha^{-1}) of the best four entries and the reference cultivar in five comparative yield trials at Coebiti and Kabo in the period 1975-1982.

Entry	Yield	Entry	Yield
TVu 4557	1.18	TVx 13-31K	1.23
TVu 2616P-01D	1.18	TVx 309-1G	1.13
TVx 13-2E	1.17	TVx 7-5H	1.11
TVx 2251	1.05	TVx 6-4H	0.87
reference (Blackeye)	0.49	reference (African Red)	0.70
TVx 66-2H	1.09	TVx 1193-7D	1.58
Vita-3	1.04	TVx 2394-02F	1.45
TVx 33-1G	1.03	TVx 309-1G	1.42
TVx 1836-9E	1.03	TVx 2394-01F	1.41
reference (African Red)	0.96	reference (African Red)	1.25
TVx 3404-012E	1.52		
Vita-6	1.48		
TVx 309-1G	1.44		
TVx 1836-013J	1.44		
reference (African Red)	1.44		

material in terms of a more even ripening, an upright determinate growth habit, and pods held above the foliage. A problem was seed size and colour. Most of the IITA cultivars had a 100-seed mass of about 10 g or less, and blackeye and creampea types were rare amongst this material. Most had uniformly brown seeds, were of the browneye type or had mottled seeds. A promising cultivar was TVx 1836-013 J, with a 100-seed mass of 17 g and ovoid to rhomboid

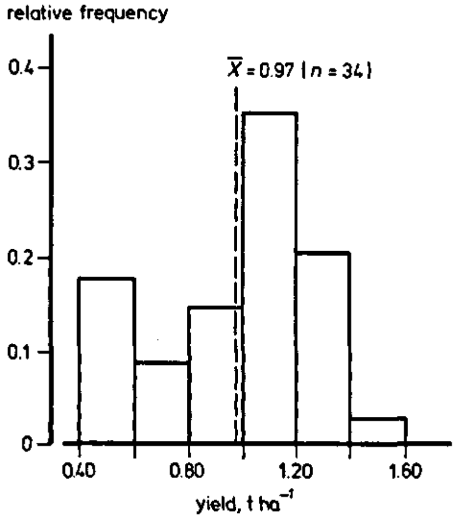


Fig. 61. Frequency distribution of experimental cowpea yields under current cultural practices. 1972-1982.

uniformly brown seeds. The cultivar has not yet been tested for its performance on a larger scale.

7.2.3.2 Yields

The seed yields obtained in the field experiments ranged from 0.42 to 1.47 t ha^{-1}, with an average (n = 34) of 0.97 t ha^{-1} (Fig. 61). These data include all field experiments with the standard methods irrespective of the cultivar or the planting date; for the variety trials the average yield of the best four entries was taken. Yields higher than 1.2 t ha^{-1} were obtained in about 23 per cent of the experiments. Low yields were obtained from out-of-season sowings. The results indicate that yields of 1.25 t ha^{-1} are feasible. To ensure that quality seeds are harvested the pods should ripen in the dry season. Taking into account its short growing cycle, cowpea should therefore not be sown early in the rainy season. Too few field experiments were done with cowpea to allow for conclusions to be drawn about this (Fig. 21, Section 6.1.2). Cowpea was never sown in February, April, May or October, and only once in March. Yields higher than 1.25 t ha^{-1} were recorded for plantings from August to January.

7.2.3.3 Plant density and spacing

Cowpea is normally planted in rows 50 cm apart. IITA prescribed a plant spacing of 50 x 20 cm, corresponding with 100 000 plants ha^{-1}. At this density a closed crop canopy was only seldom obtained, suggesting that closer spacings may be possible. With mechanized sowing, the planter was adjusted to 7 or 8 seeds per metre, resulting in plant densities between 126 000 and 144 000 plants ha^{-1}, if emergence was 90 per cent.

In a field experiment with the determinate IITA line TVx 309-1G no clear effect of plant density on seed yield could be demonstrated with densities ranging from 145000 to 283000 plants ha^{-1}. Yields varied from 1.01 to 1.58 t ha^{-1}, but this variation did not correlate with density; high yields occurred at both high and low populations.

In mechanized agriculture, high plant populations may be preferred. The resulting lower number of pods per plant enhance uniform ripening by reducing the time lapse between the first and the last mature pod. A prolonged ripening period may increase crop losses, particularly during rainy periods when there is considerable risk of pod and seed deterioration.

7.2.3.4 Production potential

In the coastal area cowpea is grown on the sandy soils or as a second crop following lowland rice. As with soybean there are no reliable data on its area or production. Ter Horst (1962) estimated that about 50 per cent of the area planted to 'other grain legumes' was occupied by cowpea. Based on 1980 statistics this would come to about 95 ha.

Cowpea is grown for its seeds. The pods are picked by hand before they are completely dry. Periods of rainy weather during ripening can cause the ripe seed to deteriorate as a result of fungal and bacterial infection of the ripe pods. Regular picking rounds are necessary, thus making cowpea a horticultural rather than an agricultural crop. Cowpea is sold on the local market in the form of ripe pods.

In the project cowpea was seen as a catch crop. It can be planted late in the season when the main crop has failed or could not be timely planted. Cowpea has a short growing cycle, does not require much soil moisture and has modest nutrient demands. The main limitation to production in the humid climate of Suriname is excessive rainfall during the pod filling and ripening stages, particularly when this is accompanied by little sunshine and continuously high air humidities. Fungal infection, especially of the pods, can reduce seed yields to zero.

Table 75 summarizes the recommended cultural practices, as derived from this and other sections. As with the other crops, a steady state of soil fertility is aimed at.

7.2.4 Mungbean (Vigna radiata)

7.2.4.1 Varietal selection

Under coastal conditions the local cultivar known as katjang idju (Accession no. 68007) reaches a height of 60 to 70 cm, branches profusely and yields at a rate of about 1.20 tonnes of dry seeds per hectare. It ripens unevenly and its ripe pods tend to dehisce, especially if air humidity is low. Several picking rounds are needed to collect all the pods produced. The mechanized harvesting of such a cultivar would lead to considerable losses.

In 1978, twenty cultivars (Appendix 5) were introduced from AVRDC, Taiwan, and subjected to single-row screening at Coebiti. All introductions

Table 75. Recommended cultural practices for cowpea growing. Target seed yield is 1.25 t ha^{-1}.

Planting time	from August to January
Plant density, ha^{-1}	150 000; 40 kg seed
Cultivar	TVx 1836-013J
Soil tillage	from minimum tillage to ploughing
Crop protection	avoid humid conditions during ripening
Weed control	pre-emergence alachlor, 2.4 kg a.i. per ha
Optimum $pH(H_2O)^a$)	5.2-6.0
Fertilizer rates, kg ha^{-1}	
N	none
P	10, at planting
K	40, at planting
Mg	none

[a]) To maintain the indicated pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.

Table 76. Mungbean. Performance of four AVRDC cultivars in comparison with a local cultivar. Averages of four replicates.

	Seed yield, t ha^{-1}		1000-grain mass, g	Plant height cm	Maturity days after planting
	range	average			
68007 (local)	1.20-1.62	1.34	41	75	61
M 7A	1.11-1.68	1.31	57	69	59
MG 50-10A (G)	1.24-1.36	1.30	62	55	56
MG 50-10A (Y)	1.10-1.51	1.29	69	40	55
PHLV 18	0.90-1.70	1.29	59	51	56

matured in a shorter time than the local cultivar; some were taller and others were shorter. Generally yields were low but most introductions yielded more than the local cultivar. Twelve cultivars were selected for further observations. Four of them were eventually carried forward to a comparative yield experiment at Coebiti. In the observation trial their yields were higher, their seeds larger and their plants shorter than those of the local cultivar. They also matured somewhat earlier.

No significant yield differences ($P = 0.05$) were observed, but the average yield of the local cultivar was highest (Table 76). There were large differences in yield between plots of the same cultivar, especially of the cultivar PHLV 18. No obvious explanation was available for this; it could not be ascribed to differences in soil fertility. Pod dehiscence was not observed in the AVRDC cultivars. The pod halves were so hard to open that the pods of PHLV 18 and MG 50-10A (G) were even difficult to thresh. At the end of the project these AVRDC cultivars had not yet been tested on a large scale.

7.2.4.2 Yields and cultural practices

Except for the variety trial mentioned above, all experiments were conducted with the local mungbean cultivar 68007. The seed yields ranged from 0.30 to 1.34 t ha^{-1}, with an average (n = 16) of 0.77 t ha^{-1} (Fig. 62). Yields higher than 1.0 t ha^{-1} were obtained in four experiments and yields lower than 0.6 t ha^{-1} in five experiments. Most of the low yields were the result of water shortage caused by planting too late in the dry season. Crop failures resulting from insect or disease problems were never observed.

No planting-date experiments were done with mungbean, and not enough experiments with mungbean were done to be able to draw any conclusions about possible effects of planting date (Fig. 21, Section 6.1.2).

The planting seasons of mungbean can be expected to coincide with those of cowpea. The two crops have an equally short growing cycle and their pods quickly deteriorate when ripening coincides with a humid cloudy period. The crop was usually planted in July-August or in January, i.e. in the second half of the rainy seasons, to avoid such problems. These growing seasons are characterized by drought periods of varying lengths; their effect on yield depends on the developmental stage of the crop. This may explain the large variations in yield of both mungbean and cowpea.

No experimental data are available on optimum densities or spacing arrangements. Mungbean was planted in rows 50 cm apart. As to the plant distance in the row, the same holds for mungbean as for cowpea (Section 7.2.3.3).

7.2.4.3 Production potential

Mungbean or green gram is planted to a limited extent on the sandy ridges of the coastal area. The crop is grown for its dry seeds, mostly used for preparing bean sprouts as a vegetable. No data on area or production are available.

Like cowpea, mungbean was seen in the project as a possible catch crop. Though the two crops have much in common, the specific use of mungbean would restrict its area planted, and consequently, mungbean received less attention than cowpea.

As for cowpea, the main limitation to mungbean production is excessive rain-

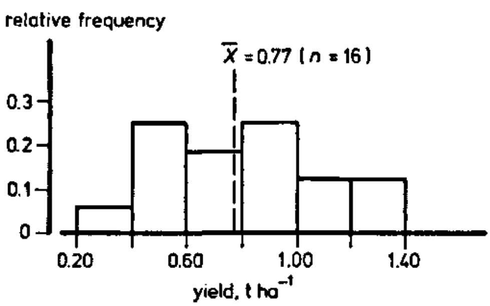


Fig. 62. Frequency distribution of experimental mungbean yields under current cultural practices. 1972-1982.

Table 77. Recommended cultural practices for mungbean growing. Target seed yield is 1.25 t ha^{-1}.

Planting time	January or July-August
Plant density, ha^{-1}	150 000; 10 kg seed
Cultivar	see Table 76
Soil tillage	from minimum tillage to ploughing
Crop protection measures	avoid humid conditions during ripening
Weed control	pre-emergence alachlor, 2.4 kg a.i. per ha
Optimum pH(H_2O)[a])	5.2-6.0
Fertilizer rates, kg ha^{-1}	
N	none
P	10, at planting
K	40, at planting
Mg	none

[a]) To maintain the indicated pH, $CaCO_3$ should be applied annually at a rate of 1 t ha^{-1}, preferably before the short rainy season and before planting groundnut or soybean.

fall during the pod filling and ripening stages. The pods and seeds are readily attacked by fungi when the ripening coincides with a cloudy humid period. Though the seed losses can be considerable, seed deterioration appears less a problem in mungbean than in cowpea. No serious diseases or insect pests were observed.

Table 77 summarizes the recommended cultural practices, as derived from this and other sections. Where no experimental data for mungbean were available, the recommendations for cowpea were used. As with the other crops, a steady state of soil fertility is aimed at.

7.2.5 Pigeon pea (Cajanus cajan)

7.2.5.1 Yields and cultural practices

The first Coebiti observation trial with four indeterminate pigeon pea cultivars showed a good vegetative growth, but few flowers and pods, and the ripening pods appeared to be very susceptible to fungal infection. It was then thought that the use of determinate cultivars and a better timing of the ripening stage could reduce these problems.

Six cultivars received from IITA were planted at Coebiti in May 1975 so that the ripening of the pods would coincide with the long dry season. Rows were 75 cm apart and plant distance in the row was 15 cm. Specific inoculum was used and the crop was fertilized at the rate of 25 kg N, 25 kg P and 25 kg K per hectare. The plants were sprayed regularly with monocrotophos. Many plants died as a result of *Rhizoctonia* infection, enhanced by extremely wet weather. At harvest 14-38 per cent of the plants had been lost.

Most pods could be harvested 134 days after planting but, in various cultivars, ripe pods were picked until many weeks later. The yields (Table 78) were mediocre, which was at least partly because so many plants had been lost. Al-

Table 78. Pigeon pea. Performance of six IITA cultivars, May-October 1975. From Bink (1976a).

Cultivar	Date[a]) of first flower	pod	harvest	Plant height cm	Seed yield g plant^{-1}	t ha^{-1}	Discoloured seeds, %
3D 8104	93	123	141	151	19	1.72	12
3D 8125	84	117	134	116	13	1.20	11
3D 8111	80	112	127	120	11	0.95	12
3D 8129	85	121	134	135	11	0.94	18
3D 8126	82	117	134	124	10	0.93	12
3D 8127	84	119	134	120	9	0.84	13

[a]) Days after planting.

though pods ripened in the long dry season, at least 10 per cent of the seed had deteriorated as a result of fungal infection.

7.2.5.2 Production potential

Although pigeon pea is by far the most important pulse crop of the lowland tropics (Rachie & Silvestre, 1977), in Suriname it has been grown to a limited extent in the coastal area, mainly in kitchen gardens (Ostendorf, 1962). In 1980 the crop was scarcely grown.

Mechanized harvesting of green or ripe pigeon peas would require a uniformly ripening crop. This may be achieved by using short statured, determinate cultivars and high plant densities. The length of the growing cycle should match the long rainy season so that the crop ripens during the long dry season. Part of the problem of pod and seed mould might be overcome by harvesting the green seeds, but the technology to do this was not available in Suriname. On the other hand, unless pigeon pea harvesting can be mechanized there is little point in solving the agronomic problems that still beset its cultivation in Suriname.

7.3 Root and tuber crops

7.3.1 Cassava (Manihot esculenta)

7.3.1.1 Clonal selection

The first cassava collection at Coebiti was planted in 1973 and comprised 33 entries of various origins (Appendix 5). In 1974 these clones were screened for their production potential in relation to growing periods of 6, 9, 12 and 15 months (Bink, 1976c). Based on their performance 6 and 8 months after planting, nine clones were selected for further comparison (Bink, 1976d). The fresh root yields 12 months after planting ranged from 16 to 41 t ha^{-1}; no outstanding clone was selected (Table 79A).

In July 1978 five clones were introduced from CIAT, Colombia, and after

Table 79. Cassava. Fresh root yields (t ha^{-1}) 12 months after planting. A. Nine clones at Coebiti. From Bink (1976b). B. Five clones from CIAT and cv. Indische Stok. Kabo.

A		B	
Clone	Yield	Clone	Yield
Bitter III	41	MCol 1684	67
Bitter V	39	HMC 2	65
Miss Jane (donker)	29	HMC 1	64
2124	28	HMC 7	54
2106	27	Indische Stok	50
2078	26	CM 323-375	49
2219	21		
Bitter IV	17		
Mantequeira	16		

some multiplication they were compared with the local clone Indische Stok in a trial planted at Kabo in 1979. All imported entries were of the low-branching plant type and four of them were bitter. Fresh root yields 12 months after planting ranged from 49 to 67 t ha^{-1} (Table 79B). None of the CIAT clones outyielded Indische Stok by 50 per cent or more, a criterion used by CIAT (Castro, 1977) for selecting clones better than the local material. The somewhat lower production of Indische Stok could be partly the result of its susceptibility to *Cercospora* leaf spot.

7.3.1.2 Yields and cultural practices

In the earliest trials at Coebiti, comprising four clones on two soil types, a sand and a sandy loam, a production level of 25-45 t ha^{-1} was obtained 12 months after planting, with negligible differences between the two soil types (Van Marrewijk, 1974). In later experiments, with Indische Stok yields were about 20 t ha^{-1}. The high yields obtained at Kabo (Table 79B) were ascribed to the relatively fertile soil of the trial site, which was rich in organic matter. Yields of 25-30 t ha^{-1} fresh roots seem more representative for soils of the Zanderij formation.

Provided the soil is not too wet nor too dry, cassava may be planted year-round. Shifting cultivators plant at the onset of the rainy season following slash-and-burn in the dry season. Based on the rainfall distribution pattern, CIAT considered the second half of the long rainy season as the best planting time (Castro, 1977). Planting before the long dry season would enhance rooting depth, thus reducing possible drought stress and with a growing cycle of 12 months, avoiding a possible decrease in root or starch yield during the long dry season. However, no conclusions can be drawn from the few cassava experiments that were conducted.

Cassava was normally planted at a row distance of 1.00 m and a density of about 10 000 plants ha^{-1}. Mechanized harvesting may require special row arrangements depending on the width of the lifting equipment and the tractor used.

In a plant density trial of the fan design with Indische Stok, root yields 12 months after planting gradually decreased as plant population increased (Fig. 63). In a second experiment cassava was planted in rows alternately 75 and 115 cm apart, to facilitate mechanical lifting of the plants. Plant distance in the row was varied, to obtain densities from about 10 000 to 20 000 plants ha^{-1}. The yields in this trial 12 months after planting varied little with density.

For Indische Stok it can be concluded that root yields do not increase at densities above 10 000 plants ha^{-1}.

7.3.1.3 Production potential

In Suriname, cassava is an important staple food for people of the country's interior who have techniques for processing the poisonous roots into non-poisonous food before they deteriorate – virtually all their cassava is bitter. These cassava types are mostly low-branching and show a large variation in colour and shape of leaves, branches and roots.

In the coastal plain, cassava is of minor importance; it is eaten only as a vegetable or used in special dishes. The clones grown in this area are sweet, non-poisonous, and mainly of the high-branching upright plant type. Amongst this group is Indische Stok. The crop is mostly harvested when the roots are still young and free from fibres.

Cassava is not grown as an industrial crop. Lack of a mechanized-harvesting technology is believed to be an important hindrance to large-scale cultivation. A further limitation when animal feed is aimed for, is the need for artificial drying, since the climate of Suriname generally is not suitable for sun drying. The equipment and energy required, however, do not make cassava an economically attractive crop for animal feed. The production of flour and animal feed would need sweet cassava, and mechanized harvesting requires easily harvestable plant types. Cassava is well adapted to the lowland tropics because of its

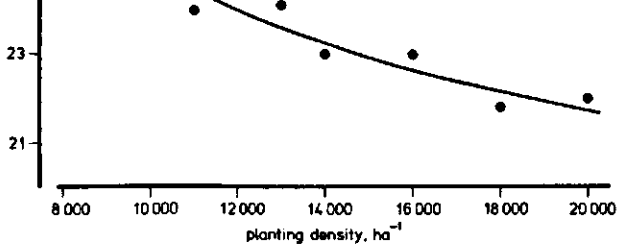


Fig. 63. Cassava cv. Indische Stok. Fresh root yields in relation to plant density.

tolerance to low levels of nutrients and high acidity. No serious constraints from disease or insect pests were observed during the project (Sections 6.7.1.4 and 6.7.2.3).

7.3.2 Sweet potato (Ipomoea batatas)

7.3.2.1 Clonal selection

Five clones from AVRDC were entered in a replicated comparative yield experiment at Coebiti in the long rainy season of 1978. The local clone Blauwkop was included as reference. Two reference plots were planted per replicate. The fertilizer applications were 30, 60 and 90 kg ha^{-1} for N, P and K, respectively. The crop was grown on ridges 90 cm apart; plant distance in the row was 30 cm.

No diseases or pests of any importance were observed. The crop was harvested 16 weeks after planting, except for one of the two plots with Blauwkop in each replicate which was left for nine more weeks. The results for Blauwkop (Table 80) suggest that harvesting at 16 weeks after planting was too early. The yield of Blauwkop doubled when left for nine more weeks but its production still remained well below that of the AVRDC introductions. A simple test showed that the boiled tubers of Blauwkop were more acceptable than those of the introductions. According to local taste, sweet potatoes should not be too sweet nor too soft when boiled.

7.3.2.2 Production potential

In Suriname sweet potato is a crop of minor importance. It occurs throughout the country in compounds or kitchen gardens and is used mostly for home consumption – very little enters the market. Only the tubers are eaten.

Sweet potato could be a suitable crop for both rainy seasons. The sandy texture of the Zanderij soils and the rainfall distribution, however, pose some special problems to the management of this crop, particularly when mechanized. There are two fairly restricted periods suitable for planting, i.e. the first two months of both rainy seasons.

Table 80. Sweet potato. Performance of five AVRDC clones and the local clone Blauwkop.

Clone	Harvesting date[a])	Marketable tubers		Fresh tuber yield, t ha^{-1}
		number per plot	mean weight, g	
I 117	16	165	217	17.6
AIS 209-3	16	202	174	17.6
AIS 479-1	16	187	177	16.6
AIS 0122-3	16	158	174	14.6
AIS 478-1	16	138	198	13.7
Blauwkop	16	89	98	5.1
Blauwkop	25	129	169	10.6

[a]) Weeks after planting.

7.4 Other crops

Cropping systems for the Zanderij soils at one stage or another may require cover crops in the rotation or crops for the production of mulch or organic material. A number of candidate legumes were observed at Coebiti for this purpose (Table 81).

7.4.1 Cover crops

Of the species listed in Table 81, *Pueraria phaseoloides* or kudzu proved the best cover crop for the Zanderij soils. On recently cleared, unfertilized soil its growth was poor because of lack of phosphorous, but once the soil had been cropped and fertilized a few times, kudzu established easily and formed a dense cover little affected by drought. Its aggressive growth can form a threat to annual crops, especially when the plant is left uncontrolled in fields lying fallow, along roads or field edges. Seed production is very poor, however.

With *Psophocarpus palustris* no soil cover was obtained. Seedlings stopped growing soon after emergence. Leaves were small and yellow.

The two *Flemingia* species remained small too, flowered very early and produced very little vegetative growth. *Calopogonium mucunoides* and *Centrosema pubescens* covered the soil well during the rainy season, but in the dry season the leaves were shed and little soil cover was left. This also applies to *Indigofera endecaphylla* and *Mimosa invisa*; during the rainy season their vegetative growth was much less, however. The *Mucuna* spp. are annual plants suitable for one short season only and therefore not producing much organic material.

Table 81. Cover crops and crops for mulch production that were studied at Coebiti.

Accession no.	Species	Accession no.	Species
Cover crops		Shrubs	
68030	*Mucuna pruriens*	68029	*Canavalia ensiformis*
68031	*Mucuna* sp.	68084	*Crotalaria usaramoensis*
68069	*Psophocarpus palustris*	68085	*C. juncea*
68071	*Calopogonium mucunoides*	68086	*C. quinquefolia*
68072	*Centrosema pubescens*	68087	*C. anagyroides*
68081	*Indigophera endecaphylla*	68088	*C. incana*
69293	*Mimosa invisa* var. *inermis*	68089	*C. striata*
79005	*Flemingia vestita*	68090	*C. polysperma*
79006	*F. fruticulosa*	68091	*C. spectabilis*
–	*Pueraria phaseoloides*	68092	*C. falcata*
		78023	*Flemingia congesta*
Trees		79001	*Tephrosia candida*
78001	*Leucaena leucocephala*	79002	*T. noctiflora*
79009	*Leucaena piracicaba*	79003	*T. vestita*
–	*Gliricidia sepium*	79004	*T. speciosa*

7.4.2 Crops for production of mulch or green manure

Canavalia ensiformis and the *Tephrosia* spp. appeared unsuitable because of too little vegetative growth. *Flemingia congesta* had an extremely slow start but once established, showed a steady growth without symptoms of deficiency or toxicity. The plant could be regularly cut back without dying. Seed production was abundant. This species merits further study as a mulch supplier on the Zanderij soils.

Crotalaria falcata, *C. anagyroides* and *C. striata* had a growing cycle of 6-8 months. Judging from the height they reached, a good amount of organic material was produced. The amounts were not recorded. The other *Crotalaria* species ceased growth much earlier and were less suitable for mulch production. *Crotalaria* could be cut back provided this was done before flowering. Once in bloom the plants usually died when clipped. Though pods were often attacked by borers, seed production was normally not a problem. Volunteer seedlings emerging from shattered seeds were sometimes a nuisance in grain legumes, as the selective herbicides for these crops did not affect *Crotalaria*.

The trees *Leucaena* and *Gliricidia* are used in alley-cropping systems elsewhere in the tropics. In June 1978 small plots comprising 20 plants of each *L. leucocephala* and *G. sepium* were established to study their dry matter production and mineral uptake. The *Leucaena* plants were raised from seeds introduced from Beltsville, USA (PI 288004) and the *Gliricidia* plants from cuttings from a local source. *Leucaena* was inoculated with specific *Rhizobium*. The plants, transferred to the field when six months old, were planted in holes measuring 60 x 60 x 60 cm. The soil was mixed with 80 g triple superphosphate, 50 g potassium-magnesium sulphate, 100 g agricultural lime and 5 g fritted trace elements containing Mo, Zn, B, Fe, Cu and Mn, which at a plant arrangement of 2.5 x 2.5 m amounted to 24.3 kg P, 17.6 kg K, 64 kg Ca, 4 kg Mg and 8 kg FTE per hectare.

Seven weeks after transplanting all plants were cut back to about 25 cm. The dry weights of the aboveground parts were 1.42 and 1.43 kg for the *Leucaena* and *Gliricidia* plants respectively, indicating that approximately equally sized material was used. *Leucaena* flowered early and profusely, but its vegetative growth was much less than for *Gliricidia* in which no flowering was observed. When cut back four months later the total amounts of dry matter accumulated by *Gliricidia* and *Leucaena* were 7.4 and 3.2 kg, respectively. *Leucaena* again flowered early and profusely, with a very poor vegetative growth: 4.1 kg of dry matter against 45.0 kg for *Gliricidia* between December 1978 and July 1979. Root examination showed that most *Leucaena* roots were still confined to the original planting hole. These roots were very fine. Only an occasional, thicker root (2-3 mm) had penetrated the soil below the planting hole. With *Gliricidia*, however, some roots had left the original hole horizontally. These roots were up to 20 mm thick.

Because the growth of the *Leucaena* remained poor it was decided to discontinue the observations. Meanwhile seedlings of another cultivar, 'Cunningham', and of *L. piracicaba* were raised to replace the earlier introduction. Though

Table 82. *Gliricidia sepium*. Dry-matter production, nitrogen yield and nutrient removal for the cuts in the period 1979-1982.

	Date of cutting				
	July 79	Febr. 80	Sept. 80	March 81	April 82
Days since previous cutting	219	210	215	181	379
Dry matter, t ha^{-1}	3.6	3.8	12.0	8.6	21.4
N yield, kg ha^{-1}	68	69	226	166	298
kg N per tonne dry matter	18.9	18.2	18.8	19.3	13.9
Nutrient removal, kg ha^{-1}					
P	n.d.[a])	n.d.	11	10	37
K	n.d.	n.d.	65	53	133
Ca	n.d.	n.d.	160	144	124
Mg	n.d.	n.d.	48	45	27

[a]) n.d. = no data available.

both were claimed to be adapted to acid soils, they gave the same results, i.e. little vegetative growth and profuse flowering. It was concluded that *Leucaena* is not suitable for the Zanderij soils.

Gliricidia performed well without growth stagnations. Flowering occurred sporadically but no pods were formed. Between December 1978 and April 1982 the plants were cut back five times, at intervals of 6 or 7 months (Table 82). Dry matter accumulation was about 20 t ha^{-1} $year^{-1}$.

For the first four cuts nitrogen yield per tonne of dry matter was about constant, but for the last cut it was less because of the large portion of woody stems without leaves. The stems of the earlier 6- or 7- month cuttings still had most of their leaves.

Gliricidia removed substantial quantities of phosphorus, potassium, calcium and magnesium. Until 1981, the nutrient supply was more or less maintained by returning the cut material as a mulch around the plants. In March 1981 this practice was stopped thus forcing the plants to exhaust the soil. This may explain the lower amounts of calcium and magnesium removed by the cut of April 1982. No marked growth reduction was observed.

The data show that *Gliricidia* could be a useful plant for the production of nutrient-rich organic material that can be utilized as mulch or as organic fertilizer. Further research is needed on its nutrient requirements, and on its management in systems such as alley cropping.

8 Mechanized field operations

As stated in Section 1 the farming systems for the Zanderij area have to be mechanized. The appropriate level of mechanization for permanent cultivation of annual crops can only be found after in-depth analyses of farming systems, taking into account agricultural, social and economic aspects. However, insufficient data were available for such analyses.

For a full account of the aspects of mechanization see Goense (1987). The author's summary is presented in Appendix 6.

8.1 Description of the equipment used in the project

8.1.1 Tillage equipment

The effects of various types of primary tillage on yield are discussed in Section 6.3.2.

For ploughing a 3-disc plough was used, with discs of 66 cm (26 inches) diameter. Cutting the weeds with a rotary slasher, or shallow tilling was necessary prior to ploughing because otherwise the weeds were not ploughed in properly. A mouldboard plough with trashboards or skim coulters ploughs in the weeds better than a disc plough, but on recently cleared land where branches and stumps can be encountered, it must be fitted with an automatic tipping device to prevent breakage, and this makes its use rather expensive.

The chisel plough used had widely spaced tines to avoid clogging. To reach a depth of 25 cm, 10-kW rated tractor power was required per tine if the tines were spaced 25 cm apart. Since the chisel plough did not plough in the weeds and crop residues adequately, a herbicide was needed at sowing.

Rotavating was done with a rotary tiller with reversely rotating L-shaped blades. Weeds and crop residues were worked in very well and a seedbed was prepared in one pass.

The disc harrow used had 61-cm (24-inch) diameter discs. When used for primary tillage, two passes were required to reach a depth of 15 cm. Coverage of weeds and crop residues was poor.

After ploughing, chisel ploughing or disc harrowing, a secondary tillage operation was needed to prepare a seedbed. The power-driven rotary harrow that was used for this purpose had a very good levelling action and was not hindered by covered or partially covered crop residues. However, intensive tillage is not desirable on sandy soils because the soil becomes too loose. Therefore, other types of secondary-tillage implements, such as a spring-tine harrow with a levelling board, may be more appropriate for these sandy soils.

8.1.2 Equipment for planting, fertilizer and biocide application

Sowing was very successfully mechanized with a 4-row pneumatic (suction system) precision planter equipped with flat vertical discs for seed metering. This planter handled all types and sizes of seed, ranging from sorghum to groundnut, provided discs with holes of an appropriate diameter were used. Precision sowing was essential for the experimental work. For farmers a less complicated and less expensive planter will be adequate.

For direct seeding into non-tilled soil the runner openers in the planter were replaced by shovel openers. Comparison of such direct seeding with minimum-tillage sowing showed statistically non-significant differences in emergence, weed growth and yields (Table 83). With minimum tillage, rotavated strips 5 cm wide were sown using runner openers. Where heavy crop residues lead to clogging, a planter with triple disc openers is to be preferred.

Fertilizer was applied in the same operation as planting. To this end the planter was equipped with special fertilizer attachments. In this combination the 4-row planter was so heavy that it could be handled only by tractors of 55 kW or more. Lime, rock phosphate, and fertilizers after planting were applied with a broadcaster. For side dressing (in maize) a special attachment with adjustable tubes was placed behind the pendulum broadcaster to divide the fertilizer over a number of rows. The feeding devices in the applicators should be of an active type, like an auger. A fertilizer distributor with a feeding device based on gravity flow did not work. This was particularly a problem with hygroscopic fertilizer mixtures.

Granular pesticides were applied simultaneously with planting, by means of an applicator mounted on the planter. For other pesticides a tractor-mounted sprayer was used.

Mechanical inter-row weed control was done with a rolling cultivator or with parallelogram-mounted sweeps. Both machines worked well. However, mechanical weed control was abandoned because of its poor results in this wet climate.

Table 83. Effect of planting method on densities and yields of maize and weeds. No tillage. Planting in January (Exp. 1) and June 1979 (Exp. 2).

	Experiment 1 Planted		Experiment 2 Planted	
	in strips	directly	in strips	directly
Weeds				
relative density[a])	0.46	0.51	0.55	0.52
dry matter, t ha^{-1}	not determined		0.91	1.10
Maize				
plant density[b]), are^{-1}	472	544	607	587
grain yield, t ha^{-1}	2.03	2.19	1.56	1.69

[a]) At 42 days after planting.

[b]) Plant density at 21 and 42 days after planting for Experiments 1 and 2, respectively.

Grain crops. Maize, sorghum, soybean, cowpea and mungbean were harvested with a self-propelled combine harvester. The machine was one of the smallest commercially available combines. Straw walker area was 2.75 m^2 and cleaning area 2.39 m^2. For maize the combine harvester was equipped with a 3-row maize header.

Experiments with maize showed that threshing and separating losses were affected mainly by grain moisture content (Fig. 64) and hardly at all by the capacity of the machine, which in the experiments was varied from 2 to 6 tonnes of dry grain per hour. These results suggest that with yield levels of 3 to 4 t ha^{-1} the widest available maize header should be chosen to fully utilize the threshing and separating capacity of the combine harvester.

In sorghum 54 per cent of the threshing and separating losses were attributable to straw moisture content and the machine's capacity to handle straw, and 16 per cent to grain moisture content and the machine's capacity to handle grain. The sharp increase in losses when straw capacity was increased stresses the importance of keeping the header as high as possible, especially when the straw is wet (Fig. 65).

For the rather short soybean cultivars in the project a flexible cutter bar proved essential, as cutter bar losses were often high with the rigid bar used.

The uneven ripening of cowpea posed problems to direct combining from stem; green leaves gave the seeds a green coating in the threshing process. Killing the crop with a defoliant a few days before harvesting, or mowing the cowpea and leaving it on the field to dry in a swath, eliminated this problem. For the second method which would require a pick-up attachment for the combine, a

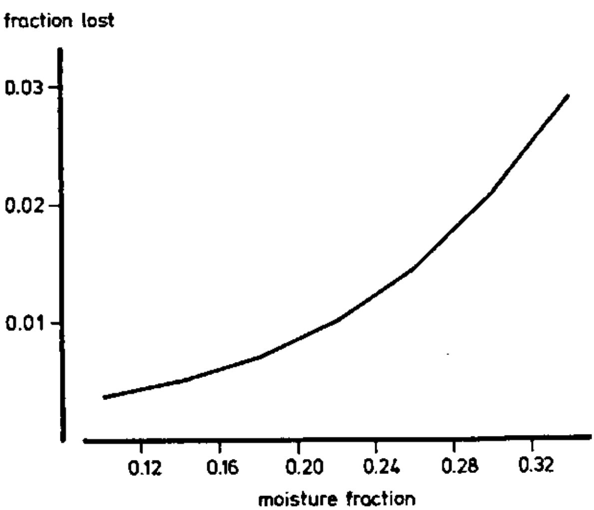


Fig. 64. Maize harvesting. Threshing, separating and walker losses in relation to grain moisture content expressed as mass fraction in moist product.

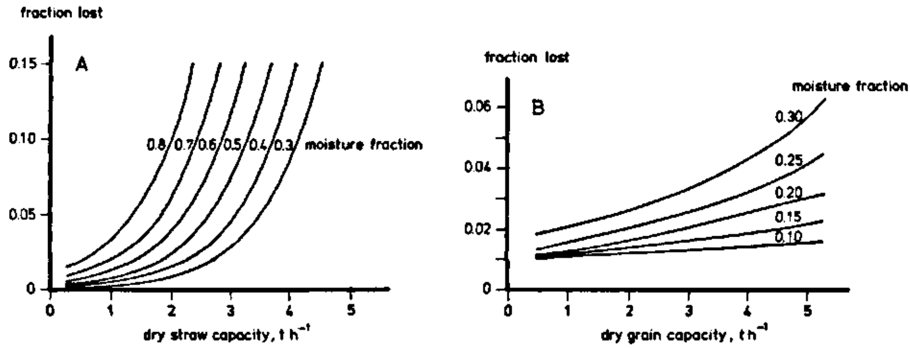


Fig. 65. Sorghum harvesting. Threshing, separating and walker losses. A. In relation to dry straw capacity and straw moisture content. B. In relation to dry grain capacity and grain moisture content. Moisture contents expressed as mass fraction in moist product.

few consecutive dry days are necessary, as rainy weather quickly leads to seed deterioration.

Groundnut. In the period 1975-77 small machinery was developed for the harvesting of groundnut (Van der Sar, 1981). Because this equipment still required 240 man-hours ha^{-1}, it will have no place in farming systems for the Zanderij area.

Machinery used in the USA for harvesting groundnut also proved successful under Suriname conditions. It proved impossible to invert Spanish-type groundnut plants with a digger-shaker-inverter because of the plants' architecture. Combining immediately after lifting resulted in many more damaged pods than combining after the lifted crop had been left in the field for a few days to dry.

Cassava. Harvesting cassava by hand is a time-consuming and strenuous operation. Two types of levers were developed in 1975 to alleviate the lifting of cassava roots (Van der Sar, 1979). The reduction in labour requirement from 171 hours ha^{-1} for the traditional method of uprooting with a fork to 136 or 63 hours ha^{-1}, depending on the type of lever used, was not sufficient to make this crop attractive in an otherwise mechanized farm system.

In 1981 experiments were conducted with a 2-row, tractor-mounted cassava digger. Before roots can be lifted the aboveground plant parts need to be removed. The machines tested for this work were a rotor mower, a flail forage harvester and a rotary cultivator with tines. The protection shield on the machines pushed over the cassava stems. As a result some plants were uprooted and their roots damaged by the cutting device. The cassava had been planted on ridges and therefore some of the stems that had fallen between the ridges were left untouched and together with weeds clogged the digger. The trial also showed that a 55-kW tractor could not handle this 1.5 m wide digger. A second lifting trial in 1982 with cassava planted on flat soil, using a 75-kW tractor was much more successful.

8.1.4 Standardization

In a mechanized farm system crop row distances should be such that there is no need to frequently change the tractor tread for different crops or operations. In the project the row distances were initially a multiple of 25 cm. Sorghum, groundnut, soybean and cowpea were planted in rows 50 cm apart. For maize and cassava the row distances were 75 and 100 cm, respectively.

The groundnut harvesting equipment from USA required rows 35, 50, 35 and 80 cm apart and a tractor tread of 200 cm (Section 7.2.2.3, Fig. 60).

Similarly, mechanized cassava harvesting led to alternate row distances of 75 and 125 cm, with a corresponding tractor tread of 200 cm.

When equipped with fertilizer and granular attachments the planter allowed only a symmetric placement of the four row units. With a row distance of 50 cm and a tread of 150 cm two row units coincided with the wheel tracks of the tractor, often resulting in poor emergence. This problem was solved by increasing the tread to 200 cm.

The final result of the various modifications was the use of two tractor treads: 150 cm for ploughing and for operations in maize, and 200 cm for the other crops. This was not too great a problem because more than one tractor was available in the project. Nevertheless, for farmers' practice the equipment should be modified further, to standardize all operations to one tractor tread.

8.2 Workability studies

8.2.1 Objectives

Not all working hours within a certain time period are suitable for mechanized field operations. Soils may be too dry or too wet for tillage, a crop may be too wet for harvesting, and rainfall may make field operations impossible. Furthermore, after-effects may occur; for example, the soil damage caused by clearing forest under too wet conditions may last for many years.

Workability is defined as the possibility that an agricultural operation can be carried out properly taking into account the conditions of machine, crop, soil and atmosphere.

For farm planning it is essential to have information on the amount of workable time available during the year. Harvesting and tilling, for instance, cannot be carried out during rainy seasons. A changeable climate means an erratic number of workable hours. The optimum machine capacity depends on the number of working hours available and on the area to be farmed. Over-mechanization leads to an unnecessary increase in production costs, whereas too low a capacity may result in planting seasons being missed or harvests postponed, with the penalty of losses.

Whether a certain period is workable or not is mostly determined by the farmer on the basis of his personal experience. The farmer's criteria must be translated into objective, measurable criteria to be able to quantify workable time. Two methods can be used to estimate workable time. The direct method is by keeping field records over a long period. Such records are scarce and not available for newly developed areas. The indirect method implies estimating the number of workable hours from long-term climatic data. Once relationships between weather variables and workability have been established, a descriptive model can be formulated. The latter method was followed in the project.

8.2.2 Workability for tillage

8.2.2.1 Experimental

During the short rainy season 1978-79 field records were kept on workability for ploughing, harrowing and planting. Once or twice a day a small area at Coebiti was ploughed, harrowed and planted. The clay contents of the 0-20 cm soil layer were between 100 and 200 g kg^{-1}. Before operations started, soil samples were taken from 0-20, 20-40 and 40-60 cm depth, to determine soil moisture content. Workability was assessed on the basis of three classes: too dry, too wet or workable.

During a rainless period the soil dried up and became so hard that the intended ploughing depth of 25 cm could not be attained; the mass ratio of moisture to dry soil in the 0-20 cm layer was then 0.115 or less.

Slip of the tractor tyres increased as soil moisture content increased. A slip fraction of more than 0.4 was considered unacceptable; the corresponding mass ratio of moisture to dry soil was 0.161. In conclusion, only if the mass ratio of moisture to dry soil was between 0.11 and 0.16 were conditions workable for ploughing.

A second experiment was carried out in April-May 1980. This period was very wet, resulting in non-workable conditions. When ploughing was possible, the mass ratio of moisture to dry soil was 0.16 or less.

As discussed by Goense (1987), there was always a transition zone between workable and non-workable conditions. The values for mass ratio of moisture to dry soil mentioned above are in the middle of these zones.

In some instances ploughing was impossible, although the mass ratio of moisture to dry soil was below 0.16. Such conditions occurred either during the early morning hours, during rain, or shortly after rain, when the fallow vegetation was wet because of dew or rain resulting in increased wheel slip.

It was never too dry for harrowing with a rotary power-harrow. At mass ratios of moisture to dry soil of more than 0.148, the soil clogged the depth-control roll of the harrow. The value of 0.148 was taken as the criterion for workability.

8.2.2.2 Soil moisture model

In the model used to calculate changes in moisture content of the different soil layers it was assumed that water moves in a vertical plane only. Therefore conclusions from the model may not be valid for sloping land with lateral water movement. Details on the model used are given by Goense (1987); here only the main principles are mentioned.

Input data for the model were hourly precipitation and evaporation. The model parameters required were the soil moisture – matric head relation, permeability, leaf area index and the evapotranspiration factor specific to the crop.

In the model it is assumed that successive soil layers fill with water from the top downwards and that the entire pore volume of each layer is filled. Six soil layers were distinguished: 0-10, 10-20, 20-40, 40-60, 60-100 and 100-500 cm. Changes in moisture content were calculated as the result of infiltration, evaporation, transpiration, and moisture flow between soil layers. Time steps varied from 0.01 to 1.00 hour, based on the constraint that moisture flow between two soil layers would not exceed one-third of the difference in moisture contents. The depth of the groundwater in the Zanderij area being 5 m or more, and because of the coarse soil texture, it was assumed that there was no capillary rise from groundwater.

Calculated moisture contents were compared with the moisture contents measured during the first experiment discussed in the previous section, for a soil under stubble and a ploughed field (Fig. 66 and Table 84). The agreement was better for the topsoil than for underlying soil layers, and better for the soil

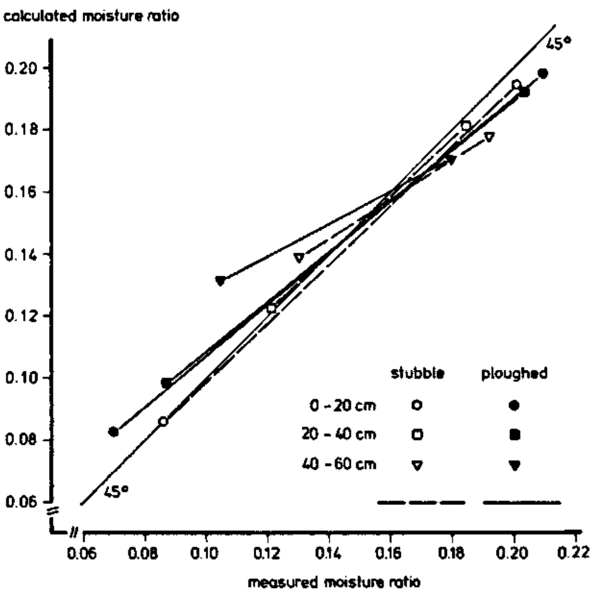


Fig. 66. Regression lines for the relations between calculated and measured mass ratio of moisture to dry soil, for soil under stubble and for ploughed soil, and for three depths.

Table 84. Correlation coefficients (r) and roots (× 100) of the mean squares (rms) of the differences between calculated and measured soil moisture contents, for soil under stubble and for ploughed soil, at three depths. n = number of observations.

	Depth, cm	n	Range[a])	r	rms
Stubble	0-20	59	0.086-0.200	0.94	0.81
	20-40	59	0.121-0.185	0.89	0.82
	40-60	59	0.130-0.192	0.84	0.72
Ploughed	0-20	58	0.070-0.209	0.93	1.22
	20-40	58	0.087-0.203	0.88	1.29
	40-60	58	0.104-0.179	0.78	1.49

[a]) Range of measured moisture contents (mass ratio to dry soil).

under stubble than for the ploughed soil. As only the topsoil was considered for workability, the results obtained were judged to be good enough for further calculations.

8.2.2.3 Workable time for tillage

Workable time for tillage as depending on soil moisture content was calculated for each hour of the 25-year period between 1 January 1958 and 31 December 1982. The available time did not include Sundays and holidays. Normal working hours were from 07.00 to 15.00 h from Monday to Friday, totalling 40 hours per week. Overtime hours were between 15.00 and 18.00 h on a normal working day and between 07.00 and 15.00 h on Saturday. So, including overtime, a week comprised 63 working hours. Apart from having an indirect effect through soil moisture, rainfall also directly affected workability: hours with 0.5 mm or more rain were considered not workable.

Fig. 67 and Fig. 68 show the average number and the dependable level for

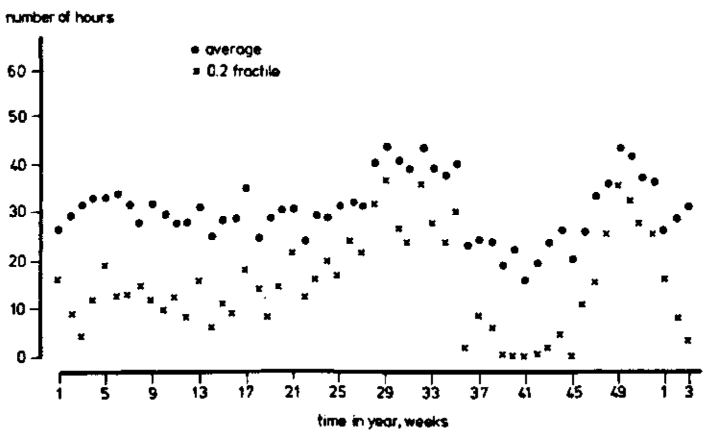


Fig. 67. Average and 0.2 fractile of the number of workable hours for disc ploughing in a week.

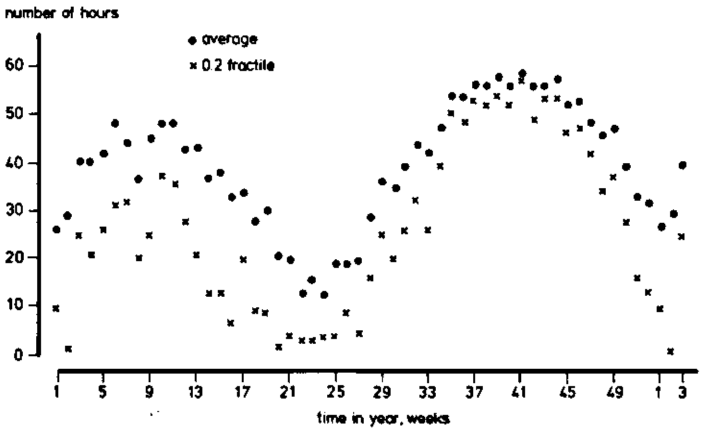


Fig. 68. Average and 0.2 fractile of the number of workable hours for harrowing in a week.

20 out of 25 years (the 0.2 fractile) of workable hours per week for disc ploughing and harrowing, respectively. During the short dry season conditions that are too dry or too wet for ploughing may occur; in the long dry season ploughing is limited by too dry conditions. As it is never too dry for harrowing, the working time for harrowing exceeded 50 h per week, i.e. 80 per cent during the long dry season. In the rainy season, about 50 per cent of the time proved workable for ploughing, but for harrowing this percentage was only about 30.

8.2.3 Workability for planting, fertilizer and biocide application

In the experiment during the 1978-79 short rainy season (Section 8.2.2.1) the workability for planting was also studied.

From a technical point of view it was never too dry for planting, but seeds do not germinate when the soil is too dry. It was not possible to formulate criteria for good emergence for the crop studied, sorghum. Different crops require different soil moisture contents for germination and emergence.

The workability criterion of a mass ratio of moisture to dry soil of 0.148 in the 0-20 cm layer as established for harrowing, can also be used for planting. At this moisture content soil started to clog the furrow openers.

No research was done on workability for fertilizer application, spraying, stubble tillage and no-tillage planting. Certainly, the first two operations will not be hindered by too dry conditions. The criterion for ploughing, i.e. a mass ratio of moisture to dry soil of 0.16, can also be applied to identify conditions that are too wet for these operations.

8.2.4 *Workability for harvesting*

8.2.4.1 *Experimental*

The requirements for workable conditions of combine harvesting are
- the weather should not interfere with the operation;
- the soil should allow movement of combine and transport equipment;
- the material to be harvested should allow mowing or picking, threshing and separation within relevant limits of loss of the product and wear of the machine;
- the moisture content of the product should be sufficiently low for safe immediate storage or for drying.

The main determinant is moisture content. The moisture content of the grain affects grain quality and product damage, that of the straw affects product loss and machine wear. Besides the moisture in the plant parts, there is moisture in the so-called reservoir, i.e. moisture adhering to and collected around plant parts. The moisture content of the reservoir decreases by evaporation and by diffusion into plant parts.

The moisture content of the grain changes during the day. The changes were measured in a number of field experiments. On three dates, 18 and 24 November and 21 December 1982, five crops were planted: maize, sorghum, soybean, groundnut and cowpea. Starting at the crop's maturity, a small plot of each crop from each planting was harvested, threshed and sampled for moisture determination. Sampling was carried out between 07.30 and 18.00 h at a frequency of up to six times a day. Groundnut pods were sampled from windrowed material.

The daily fluctuations in the moisture content of maize and groundnut were small. For maize a gradual decrease after maturity was observed, the rate of decrease depending on weather conditions. The moisture content of groundnut pods depended on the extent to which any rainfall in the previous days had reached the crop via the soil under the windrow.

Grain moisture contents of sorghum, soybean and cowpea changed daily (Fig. 69). On dry days the effects of rain on previous days were visible until about 14.00 h for sorghum and cowpea and the whole day for soybean.

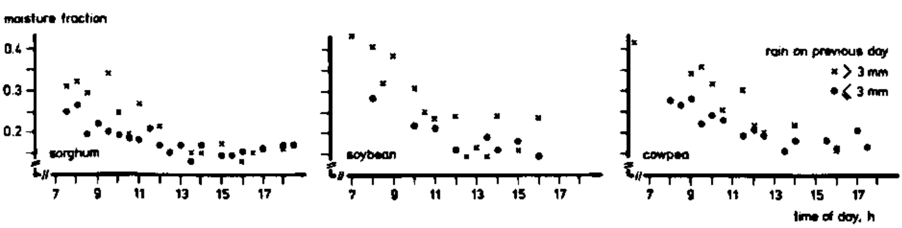


Fig. 69. Course of grain moisture content, expressed as mass fraction of moist grain, during dry days.

8.2.4.2 Grain moisture model

To estimate workable hours for combine harvesting a model was developed that calculates the moisture content of the reservoirs as a result of rain, condensation, evaporation, and diffusion into grains, and that of the grains as a result of diffusion into the grains, exchange with the ambient air, and radiation. For details see Goense (1987). Input data were grain dry matter per ha, maximum grain moisture content, coefficients for calculating equilibrium moisture content of the grain, and hourly meteorological data. As a rule, the time step was one hour, except for periods with an evaporating reservoir, when a step of 0.1 hour was used.

The model was calibrated with the results from the experiments mentioned in Section 8.2.4.1 and evaluated for maize with the results from the experiments mentioned in Section 8.3.2.1.

For maize, sorghum, soybean, groundnut and cowpea the presence of a reservoir was observed in the field and predicted by the model in 77 per cent of the 200 cases; observed but not predicted in 12 per cent of the cases and not observed but predicted in 11 per cent of the cases. The model's performance in calculating grain moisture content was satisfactory, provided that the crops and circumstances were similar to those prevailing in the experiments used for calibrating the model: correlation coefficients ranged from 0.82 to 0.92 and the average root of the mean squares of the differences between calculated and measured moisture contents was 0.032 and the measured moisture contents in moist grain ranged from 0.09 to 0.52.

8.2.4.3 Workable time for harvesting

The presence of adhering moisture and the grain moisture contents were calculated with the model for a 25-year period (1958-82) divided into one-week intervals. Crops were assumed to be mature at the beginning of an interval. Grain moisture content at maturity was set at 0.31 for maize and at 0.26 for sorghum, soybean and cowpea. It was assumed that groundnuts were lifted at the beginning of the week and that pod moisture content was 0.45. Conditions were considered non-workable if:

- more than 0.5 mm rain had fallen in the preceding hour;
- mass ratio of moisture to dry soil was 0.16 or more for combine harvesting (the same criterion as for ploughing), and 0.148 or more for groundnut stripping;
- a moisture reservoir was present;
- grain moisture content was more than 0.28 for maize and more than 0.24 for sorghum, soybean, groundnut and cowpea.

Total available working time was 63 hours per week (Section 8.2.2.3). Fig. 70 shows that there was not much workable time for harvesting during the long rainy season. There was generally more workable time for harvesting maize than for harvesting other crops. Groundnut harvesting in the first week after lifting was possible during the dry seasons only.

As the limits that were used for grain moisture content were relatively high, the calculated workable time can be considered as the maximum possible.

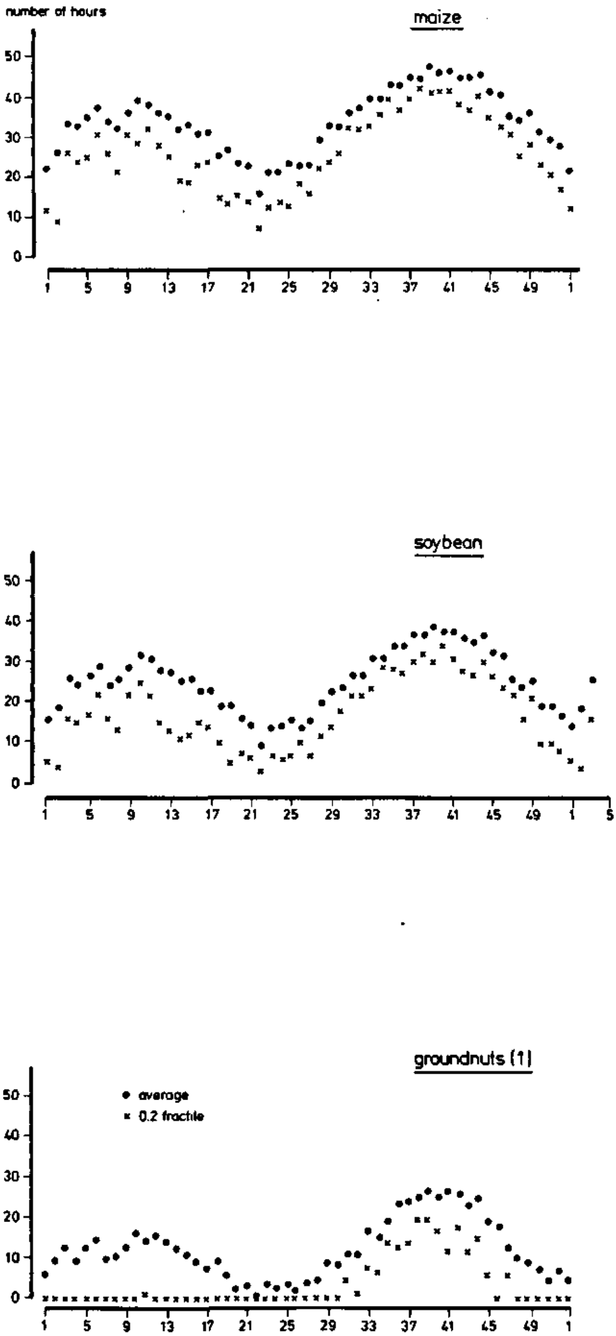
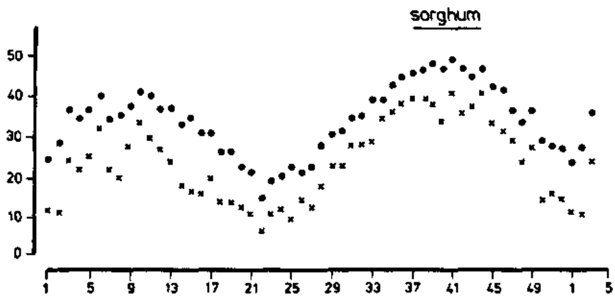
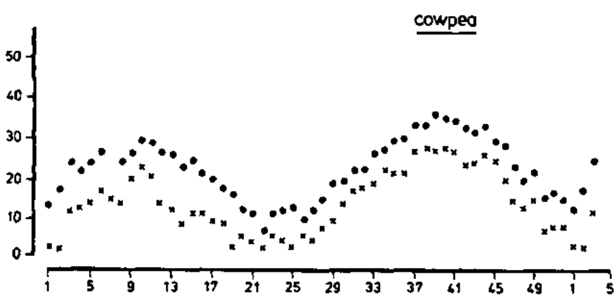
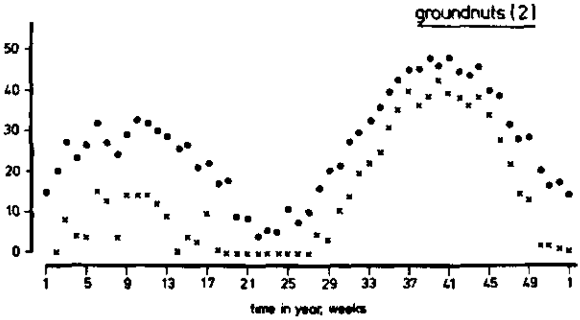


Fig. 70. Average and 0.2 fractile of the number of workable hours for harvesting in a week. Groundnuts (1), (2) = first and second week in windrow, respectively.


sorghum
50
40
30
20
10
0
1
5
9
13
17
21
25
29
33
37
41
45
49
1
5


cowpea
50
40
30
20
10
0
1
5
9
13
17
21
25
29
33
37
41
45
49
1
5


groundnuts (2)
50
40
30
20
10
0
1
5
9
13
17
21
25
29
33
37
41
45
49
1
time in year, weeks

8.3 Timeliness studies

8.3.1 Objectives

Timeliness is the possibility that a given operation can be carried out at the moment that the quality and quantity of the product are optimum. The timeliness function relates the relative loss of crop value, i.e. compared with the maximum possible value, to the number of days that the operation is carried out earlier than or later than the optimum moment.

There are optimum times for the consecutive field operations. In practice it is not possible to carry out all operations at the optimum moment and a compromise has to be made between the costs of machine capacity and timeliness costs. The timeliness functions of the field operations need to be known for agricultural planning. In the project the sowing of maize and the harvesting of maize, sorghum, soybean and groundnut were studied. The results of maize sowing studies were presented in Section 6.1 and therefore only the research on timeliness of harvesting is discussed here.

Crop yield is maximum when the crop is physiologically mature. Crop losses in the period between physiological maturity and harvesting result from bird damage, shattering, rot, respiration, and lodging (the latter makes mechanized harvesting impossible). To avoid such losses, crops should be harvested as soon as technically feasible. Crops that must be threshed require some time after physiological maturity for drying.

Harvesting is often delayed because of unfavourable weather conditions and insufficient machine capacity. Increasing this capacity reduces the harvesting losses but increases costs. The losses resulting from postponing harvesting must be quantified so that optimum machine capacity can be calculated.

8.3.2 Effects of timeliness on harvesting

8.3.2.1 Maize

The effects of postponing the harvesting of maize under different climatic conditions were studied in three crops planted 17 March, 22 April and 13 May 1981. Mechanized harvesting started when grain moisture content was around 0.3 and continued at weekly intervals until six weeks after the first harvest. In Fig. 71 the yields are depicted by two curves; the lower one represents the measured machine yield and the upper one the apparent yield, i.e. the sum of machine yield and measured losses from threshing, cleaning and picking (ears missed by the machine). The first crop showed a sharp yield decrease for the first three harvests. A more gradual decrease was found for the second crop, whereas for the third crop postponement did not lead to yield losses (Fig. 71). Total rainfall during harvesting for the first, second and third crops was 251, 114 and 67 mm, respectively, suggesting that the weather conditions had an important influence. However, the number of planting dates and the corresponding variation in weather conditions were too small to be able to establish a relationship between

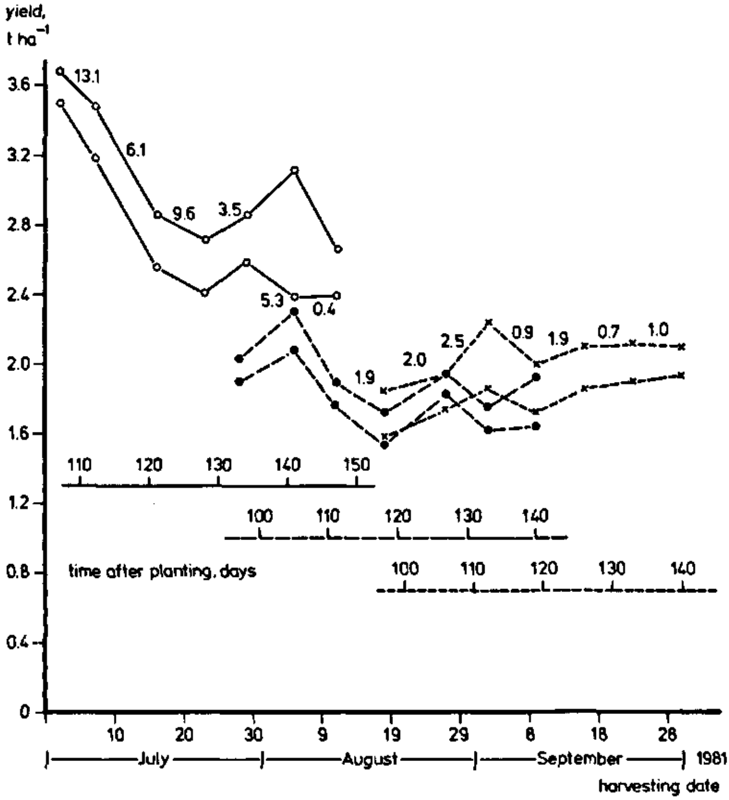


Fig. 71. Effect of postponement of harvesting on machine yields (lower curves) and apparent yields (upper curves) of maize planted on 17 March (○), 22 April (•), and 13 May (x). Numbers alongside the curves refer to rainfall (mm day^{-1}) for that period. Apparent yield defined in text.

crop losses and climatic conditions.

The yield levels for the first crop were much higher than those for the other two crops. The probable causes of the lower yields were the rather wet conditions at sowing, the leaching of fertilizers early in the growing season and the less effective weed control.

The relative differences between machine and apparent yield generally varied from 5 to 16 per cent of apparent yield. An exceptionally high loss of 23 per cent was found on 5 August for the first crop. The major part of the losses were picking losses. For more details see Goense (1987).

8.3.2.2 Sorghum

The effect of delayed harvesting for sorghum was studied in four crops planted 30 October, 24 November and 15 December 1981, and 13 January 1982. In each crop combine-harvesting was done weekly during a 5-week period following maturity. Heavy rainfall (ca. 350 mm) between 25 March and 1 April 1982 made it impossible to harvest the third crop for three weeks, whereas harvesting of the fourth crop could not start until two weeks after maturity.

Delayed harvesting led to crop losses in all four crops. The differences between machine yield and apparent yield (consisting of mowing, threshing and cleaning

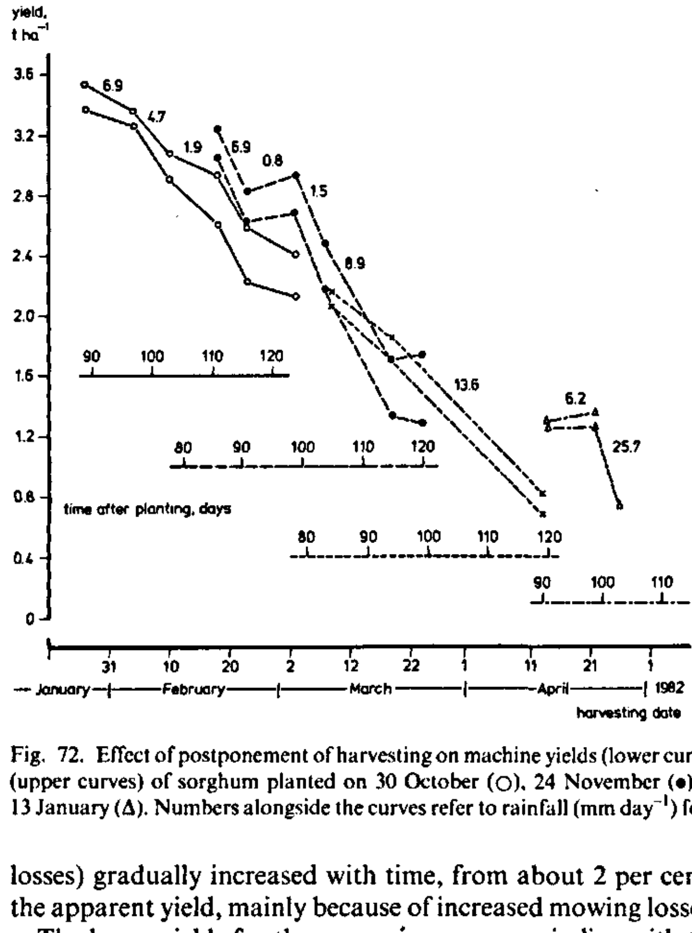


Fig. 72. Effect of postponement of harvesting on machine yields (lower curves) and apparent yields (upper curves) of sorghum planted on 30 October (○), 24 November (•), 15 December (x), and 13 January (Δ). Numbers alongside the curves refer to rainfall (mm day^{-1}) for that period.

losses) gradually increased with time, from about 2 per cent to 30 per cent of the apparent yield, mainly because of increased mowing losses (Fig. 72).

The lower yields for the successive crops are in line with theoretical expectations (Fig. 20, Section 6.1.1), but from mid-February onwards leaf diseases in the third and fourth crops also played a role. There was a very consistent trend of lower yields when harvesting had to be postponed beyond January because of continuous rain. From mid-March onwards grains started to germinate on the plants, leading to quality loss of the harvested product. For the November crop the daily loss of machine yield was 54 kg ha^{-1}; for the other crops it was between 35 and 40 kg ha^{-1}. It can be concluded that any delay in sorghum harvesting should be avoided.

8.3.2.3 Soybean

In 1983 a harvesting-date study was carried out with soybean. Two crops were planted: 17 March and 13 April; it was too wet for a third planting. As a result of wet weather the weed control in the second crop was insufficient and only four harvests were possible. Generally the yields of the second crop were lower than those of the first one (Fig. 73).

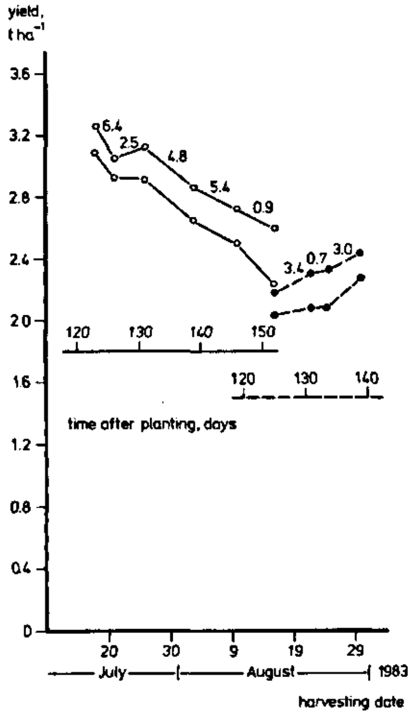


Fig. 73. Effect of postponement of harvesting on machine yields (lower curves) and apparent yields (upper curves) of soybean planted on 17 March (○) and 13 April (•). Numbers alongside the curves refer to rainfall (mm day^{-1}) for that period.

The first crop showed a yield decrease of 20-30 kg ha^{-1} for each day the harvest was postponed. For the second crop delaying harvesting did not result in yield decreases, probably because of lower rainfall during harvesting (Fig. 73). The longer the harvest was delayed, the greater the mowing, threshing and cleaning losses of the first crop. These losses varied from 4 to 14 per cent of the apparent yields. For the second crop these losses varied between 6 and 11 per cent, but were not related to the period of postponement.

It may be concluded that timeliness losses for soybean harvesting are rather unimportant, provided harvesting takes place when conditions are not too wet.

8.3.2.4 Groundnut

In groundnut cultivars like Matjan the number of pods is determined in an early stage of development but pod filling continues over a long period provided the foliage remains healthy. Consequently, early harvesting can be detrimental to yield.

Mechanized harvesting was carried out in two steps. The first step included lifting, shaking and windrowing, and the second step consisted of stripping (threshing) with a pick-up combine.

The optimum time for lifting depends on the maturity of the pods, the condition of the vines, and on the weather while the crop is in the windrow. As a rule of thumb, the time for lifting was considered to be optimum when 75 per cent of the pods showed dark discolouration on the inside of the hull.

Studies on the effects of timeliness on groundnut harvesting should include variations in the time of lifting and in the time of stripping, preferably according to an orthogonal design. In practice, however, it was not possible to maintain such ideal schemes.

Three harvesting experiments were carried out on crops planted in 1979, 1980 and 1983. The 1979 experiment suffered from leaf spot diseases and leaf rust, so that the results of this experiment cannot be considered representative. The 1980 experiment focused on the effects of postponing lifting. The 1983 experiment best approached the optimum design. There were two sowings: 14 November and 3 December 1982. The first crop was lifted 99, 102, 110, 117, 124 and 134 days after sowing and the second crop 105 and 115 days after sowing. It was intended to thresh 4 and 11 days after lifting, but weather conditions and technical restrictions prevented this. Lifting losses were determined by dig-

Table 85. Effects of postponement (days) of lifting and stripping on groundnut machine yields (t ha^{-1}).

Time of lifting[a])	Postponement of		Machine yield	Lifting loss[b])	Rainfall[c])
	lifting	stripping			
Planted on 14 November 1982; first lifting on 21 February 1983					
99	0	8	2.82	0.28	11.3
		9	2.75		10.8
102	3	6	3.07	0.31	8.3
		12	2.09		9.4
110	11	4	2.66	0.57	2.7
		12	2.72		2.2
117	18	5	2.37	0.38	0.9
		17	0.85		4.1
124	25	10	2.51	0.50	6.3
		19	0.88		6.8
134	35	9	1.06		7.5
Planted on 3 December 1982; first lifting on 18 March 1983					
105	0	10	2.69	0.48	6.3
		19	1.87		6.8
		26	0.36		8.1
115	10	9	3.25	0.62	7.5
		16	2.61		9.4

a) Days after planting.
b) See text.
c) Rainfall (mm d^{-1}) during windrow period.

ging by hand and searching 1 m of a groundnut bed (i.e. 4 rows) after the lifting machine had passed.

Table 85 shows that lifting losses increased with postponement of lifting. However, these losses were smaller than the decreases in yield obtained when stripping was postponed. This was confirmed by multiple regression analysis, from which it followed that yield losses could be described by the equation

$$L = 1.18\, x_1^2 + 4.78\, x_2^2,$$

where L = machine yield loss, kg ha^{-1},
x_1 = postponement of lifting, days, and
x_2 = postponement of stripping, days.

This equation shows that a one-day delay in stripping results in the same loss as a 4-day delay in lifting. If harvesting is to be postponed, the delay should be divided over lifting and stripping in the ratio 4:1, to minimize yield losses. This is also demonstrated by Fig. 74, where isoquants of yield losses in relation to postponement of lifting and stripping are presented.

The yield losses were probably affected by rainfall (Table 85), but the number of data was too limited to be able to separate the influence of rain from the effects of postponement of harvest.

The above equation was used to calculate the yield losses for the 1980 experiment (Table 86). These calculated losses plus the recorded machine yields were considered to be estimates of the yields that would have been obtained if the crop had been lifted and stripped at 89 days after planting. The range of these estimates was 2.08 – 2.23 t ha^{-1}, with an average of 2.17 t ha^{-1}. Subtracting the calculated losses from this average resulted in the calculated yields shown in Table 86. The latter were in good agreement with the measured yields. Although

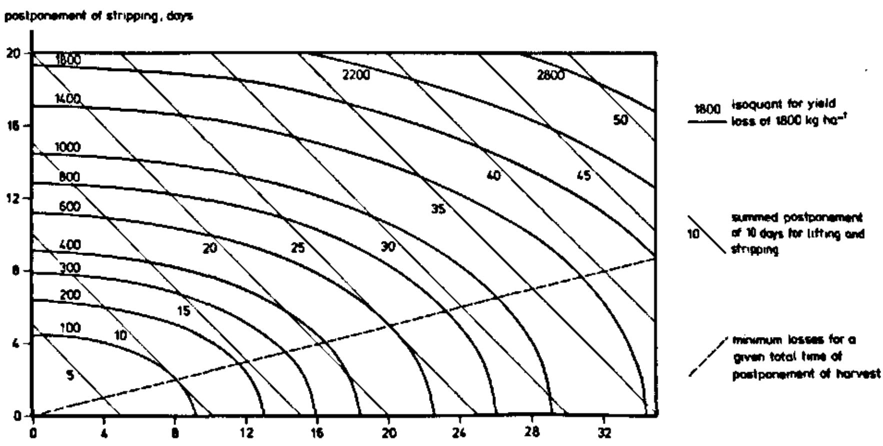


Fig. 74. Map of isoquants of losses caused by postponing the lifting and stripping of groundnut.

Table 86. Effects of postponement (days) of lifting and stripping on calculated and measured machine yields of groundnut (t ha^{-1}). Planted 17 July 1980; first day of lifting 20 October 1980. For explanation see text.

Time of lifting[a])	Postponement of		Calculated		Measured yield	Rainfall[b])
	lifting	stripping	loss	yield		
89	0	4	0.08	2.09	2.12	4.2
91	2	2	0.02	2.15	2.19	0.0
93	4	3	0.06	2.11	2.01	0.6
96	7	2	0.08	2.09	2.05	2.5
98	9	2	0.11	2.06	2.05	0.0
100	11	4	0.22	1.95	2.01	0.0

[a]) Days after planting.
[b]) Rainfall (mm d^{-1}) during windrow period.

Table 87. Effects of postponement of lifting and stripping on machine yields (t ha^{-1}) of groundnuts infected by leaf spot disease and leaf rust.

Time of lifting[a])	Postponement of stripping, days after lifting							
	0	1	2	3	4	6	9	12
Planted on 7 May; first lifting on 7 August 1979								
92	1.29	1.05	1.37		1.16	1.17	1.39	0.15
96	1.65	1.10	1.47		0.43	0.78	0.07	0.29
100	0.87	0.42	0.28		0.00	0.19	0.14	
104	0.29	0.12	0.12		0.12	0.07		
Planted on 17 May; first lifting on 18 August 1979								
93	1.88	1.44	1.51		1.00	1.09	1.13	1.07
96	1.42	0.95	1.31		1.02	0.85	0.69	0.89
99	0.49	0.64	0.55		0.69	0.85	0.33	
102	0.24		0.21		0.24			
Planted on 30 May; first lifting on 30 August 1979								
92	2.34	2.55	2.17	2.13	2.23	1.31		
94	2.59	2.11	2.21	1.85	1.89	1.83		
96	1.48	2.03	1.75	1.74	1.35			
98	1.71	1.55	1.32					

[a]) Days after planting.

the calculated yields are not independent of the recorded yields, it is probably still justified to conclude that the results shown in Table 86 do not give cause to reject the above equation.

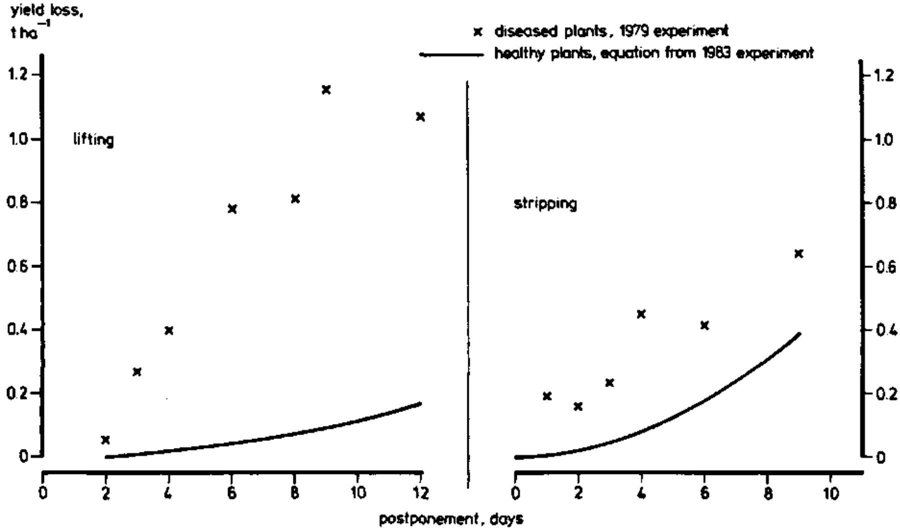


Fig. 75. Effect of postponing lifting and stripping on yield losses (t ha^{-1}) of diseased plants (1979 experiment), compared with the losses calculated for healthy plants (1983 experiment).

This was not true for the 1979 experiment, in which the plants were heavily infected by leaf spot and rust and the fields were weedy. Postponement of both lifting and of stripping resulted in much higher losses than in the 1983 experiment (Table 87; Fig. 75). The weakened vines broke during lifting and many pods remained in the soil. These results underline once more that disease control is a major requirement for groundnut growing in the Zanderij area.

In conclusion, if the crop is healthy but it is impossible to harvest at the right time, it is better to postpone lifting rather than postpone stripping, whereas if the crop is diseased it should be lifted as early as possible.

9 Synthesis: mechanized annual cropping

9.1 Aims and assumptions

In this chapter the available experimental results are synthesized into mechanized management systems for use on the Zanderij soils for each of the food crops studied except cassava. To this end it was assumed that the crops are grown on the loamy soils of plateaus and upper slopes, cleared from forest some years ago and free from remnants from the original vegetation so that there are no physical obstructions to mechanized farming. Further it was assumed that as a result of previous lime and fertilizer applications soil fertility has been improved to the steady state level (Sections 6.5 and 7), i.e. pH(H_2O) around 5.5, P-Bray-I 15 mg kg^{-1}, exch. K 0.7 mmol kg^{-1}, exch. Mg 2.0 mmol kg^{-1} (ionic equivalents).

All the field operations and crop husbandry measures including amounts of fertilizers and pesticides are presented per crop, and the costs per hectare of labour, machine use and other inputs are calculated for each crop. It should be emphasized that the quantitative information is not always firmly based on experimental results. In some instances preliminary results have been extrapolated and sometimes even assumptions have been made. It was nevertheless felt that a synthesis without an indication of production costs would not be complete.

Cropping seasons are defined and a cropping calendar has been set up taking into account the requirements of the different crops and the climate-related workability problems with soil preparation, planting and harvesting.

As yet there is insufficient experimental evidence to be able to specify which farming systems the crops studied could be part of. For instance, virtually no research was done on crop rotation. Nevertheless sufficient knowledge was available to design a cropping pattern and a labour diagram for a one-man farm on the loamy soils of the Zanderij area.

9.2 Crop production costs and returns

9.2.1 Costs of material inputs

The material inputs needed for the various crops are presented in Table 88, which was derived from the recommended cultural measures mentioned in Section 7. The table also mentions target yields as defined in Section 6.5.1, and machine yields. The difference between them was estimated from the results of Section 8. Nutrient concentrations of fertilizers and prices of fertilizers and other products (Table 89) refer to the situation in 1983. The fertilizer prices were those actually paid for medium-sized quantities off-harbour plus SRG 0.05 per kg to cover costs of transportation from dock to farm.

The prices of pesticides were prices for relatively small quantities bought from local suppliers. Inoculum not being available locally, the material was air-freighted from USA to Suriname to avoid deterioration in transport. These extra costs have not been included.

Table 88. Yields and material inputs[a]) required for crops that might be grown on a mechanized farm in the Zanderij area. Expressed in kg ha^{-1} unless stated otherwise.

	Maize	Sorghum	Soybean	Ground-nut	Cowpea[b])
Target yield, t ha^{-1}	4.5	3.5	2.5	4.0	1.25
Machine yield, t ha^{-1}	4.0	3.25	2.25	3.0	1.1
Seed	18	5	40	100	40
Alachlor	2.4	2.4	2.4	2.4	2.4
Monocrotophos, l ha^{-1}	0.5	–	–	–	–
Chlorothalonil, l ha^{-1}	–	–	–	8.75	–
Inoculum	–	–	12	12	–
Fertilizers applied at planting					
ureum	189	156	–	–	–
triple superphosphate	211	105	211	105	53
muriate of potash	100	80	120	120	80
kieserite	188	–	94	188	–
Fertilizers applied at four weeks after planting					
ureum	189	167	–	–	–
muriate of potash	100	80	120	–	–

[a]) To the inputs should be added the lime for maintaining soil pH ($CaCO_3$ at a rate of 1 t ha^{-1} per year). The quantity per crop depends on the number of crops grown per year.
[b]) For mungbean the requirements are the same, except that only 10 kg of seed is needed.

Table 89. Prices of inputs (SRG per kg) and contents of nutrients (g per kg) in the fertilizers used.

	Price	Nutrient content
Seed, maize, sorghum	1.00	
soybean, cowpea, mungbean	2.00	
groundnut	3.50	
Alachlor	26.00	
Monocrotophos (SRG per l)	26.00	
Chlorothalonil (SRG per l)	33.60	
Inoculum	2.25	
Ureum	0.47	450 (N)
Triple superphosphate	0.571	190 (P)
Muriate of potash	0.508	500 (K)
Kieserite	0.405	160 (Mg)
Lime	0.25	

Though planting material may be produced on the farm, in practice quality seed will normally be purchased from a seed firm, and therefore seed can be an important cost item, as in the case of groundnut.

The data in Table 88 and Table 89 have been combined to calculate the cost of inputs per crop per ha (Table 90). The cost of lime (SRG 250 per year) which is applied once a year is divided evenly between the crops, assuming that there are two crops per year. The cost of material inputs is by far the highest for groundnut because of the high prices of seed and fungicides (chlorothalonil), and is the lowest for cowpea and mungbean because of their modest fertilizer requirements. Maize, soybean and sorghum have an intermediate position.

9.2.2 Costs of machines

The field operations required for each crop are stubble clearing by mowing, primary and secondary soil tillage (ploughing and harrowing, respectively), planting combined with band placement of fertilizers, (planting and fertilizer application are separate operations for groundnut), pre-emergence application of the herbicide alachlor with a tractor-mounted sprayer, harvesting (for groundnut lifting and stripping with special equipment; combine harvesting for the other crops), and artificial drying of the harvested products. A second fertilizer application, side-dressed at four weeks after planting, is necessary for maize, sorghum and soybean. In addition, maize requires application of the insecticide monocrotophos, and groundnut requires five two-weekly applications of the fungicide chlorothalonil starting at four weeks after planting; both types of applications are carried out with a tractor-mounted sprayer.

It was attempted to estimate the cost of these operations. The calculations were based mostly on tractor power and equipment as used in the project (see Section 8.1). Exceptions are that a combined harvester with a slightly larger

Table 90. Cost of material inputs (SRG per ha) for various crops.

	Maize	Sorghum	Soybean	Groundnut	Cowpea[a])
Seed	18	5	80	350	80
Alachlor	62	62	62	62	62
Monocrotophos	13	–	–	–	–
Chlorothalonil	–	–	–	294	–
Inoculum	–	–	27	27	–
Ureum	178	147	–	–	–
Triple susperphosphate	120	60	120	60	30
Muriate of potash	102	81	122	61	41
Kieserite	76	–	38	76	–
Lime	125	125	125	125	125
Total	694	480	574	1055	338

[a]) For mungbean the cost of seed is SRG 20 per ha and the total cost is SRG 278 per ha.

capacity was chosen, and that a spring-tine cultivator was used for harrowing. Task times were calculated taking into account the capacity of the machines, and assuming a field size of 300 x 100 m and an average travelling distance of 500 m from farm to field (Table 91). The operations are carried out by one person, the farmer, with the exception of harvesting which is done by two persons, i.e. the contractor with the combine and the farmer with the grain transport equipment.

The task times calculated in Table 91 were used to estimate man-hour and implement hour requirements for the various crops (Table 92). The number of tractor hours required equals the sum of the implement hours except for the hours of the self-propelled combine. The number of man-hours required is the sum of tractor hours and combine hours.

Table 93 gives the cost per implement hour; it does not include interest on investment, housing, taxes or insurance. The calculation of implement hours per year is based on a farm with a cropped area of 39 ha and two crops per year, mainly soybean and groundnut (Section 9.5).

Lifetime repair costs of a machine were taken as a fraction of the new cost; fraction values were adapted from ASAE (1986) as follows. The average was calculated of the useful life working hours as assumed by ASAE and the life implement hours found in the project. The ratio of this average to the useful working hours according to ASAE, was multiplied by the lifetime repair costs given by ASAE. The reasoning behind this was that if a machine works less or more than the standard working hours, some of its repair costs will become

Table 91. Farm equipment capacities, task times and fuel consumption.

	Working width m	Working speed km h^{-1}	Product[a]) mass kg ha^{-1}	Bin capacity kg	Task[b]) time h ha^{-1}	Fuel consumption l h^{-1}
Mower	1.8	7	–	–	1.32	7.4
Plough	0.9	6	–	–	3.29	8.2
Harrow	2.8	7	–	–	0.92	6.9
Planter, maize	3.0	6	700[c])	–	1.51	5.9
others	2.0	6	700[c])	–	2.01	5.7
Sprayer	12.0	6	400	800	0.69	4.0
Fertilizer spreader	8.0	6	100-250	600	0.64	3.7
	8.0	6	250-400	600	0.72	3.7
Lime spreader	6.0	6	1000	600	1.00	3.7
Groundnut lifter	2.0	5	–	–	1.80	6.8
Groundnut stripper	2.0	5	3250	1000	2.42	6.4
Trailer, groundnut	–	–	–	–	2.42[d])	2.9
Combine harvester	3.0	6	4600	2500	1.52[d])	10.5
Trailer, other crops[d])	3.0	6	–	–	1.52	2.7

[a]) Product applied or harvested.
[b]) IMAG 56: Task times for field work, IMAG-Dataservice, Wageningen, the Netherlands.
[c]) Sum of seeds and fertilizers.
[d]) Trailer to transport the harvested products to the dryer.

Table 95. Production costs and returns for the various crops in SRG per ha.

	Maize	Sorghum	Soybean	Groundnut	Cowpea[a])
Conventional tillage					
material inputs	694	480	574	1055	338
machine costs	367	376	375	547	366
artifical drying	100	81	56	150	28
labour costs	119	117	117	184	110
total costs	1280	1054	1122	1936	842
Production, t ha^{-1}	4.0	3.25	2.25	3.0	1.1
Cost per tonne produce	320	327	499	645	765
Price per tonne produce[b])	273	286.2	525.6	718.2	600[c])
Returns	1092	930	1183	2155	660
Net balance per ha	−188	−124	+61	+219	−182
Net balance/cost	−0.15	−0.12	+0.05	+0.11	−0.22
No tillage; production set at 0.8 times production with conventional tillage					
total costs[d])	1259	1037	1110	1905	835
returns	874	744	946	1724	528
net balance	-385	-293	−164	−181	-307

[a]) For mungbean the cost of material inputs is SRG 278 (Table 90); hence total cost is SRG 782 and cost per tonne of produce SRG 711.
[b]) World market cif prices 1981.
[c]) As there is no world market for cowpea and local prices fluctuate strongly, this amount of SRG 600 should be considered as a rough estimate.
[d]) For explanation see text.

is at least partly used to pay interest on investment, housing, taxes and insurance, the net income to the farmer can hardly be positive for any crop. The cif prices used in Table 95 have to be paid if these commodities are imported from abroad. The farmers receive lower prices, and this makes it even less likely that farming will be profitable. If no tillage is practised the ploughing and accompanying tractor and labour costs (SRG 31.26 + 18.82 + 30.93 = 81.01) are saved. There are extra costs, however, for one herbicide application (SRG 62 + 7.55 + 3.95 + 6.49 = 79.99), whereas production will be about 80 per cent of that obtained with conventional tillage (Section 6.3.2.). This reduces drying costs, but also reduces the returns. The net balance is always negative, even for groundnut and soybean (Table 95), so that no tillage cannot be considered a realistic alternative for conventional tillage.

Only if inputs are subsidized or if prices that are higher than the cost prices can be guaranteed, does mechanized annual cropping have a chance. It needs to be emphasized that this conclusion is based on comparison of costs and returns per crop only. Aspects such as crop rotation and farm size have not been taken into account.

9.3 Cropping calendar

Optimum growing periods as discussed for various crops in Section 6.1 and Section 7 have been combined for various crops in Fig. 76. In this and the following diagrams the cropping year begins in Week 43, which is around 20 October. By that time the crops grown during the long rainy season have usually been harvested and field preparations for the following short rainy seasons can start. The growing periods in Fig. 76 were set at 15, 13, 16, 14, 10 and 10 weeks for maize, sorghum, soybean, groundnut, cowpea and mungbean, respectively. Maize should be grown only during the long rainy season, and sorghum only during the short rainy season. Soybean and groundnut can be grown in both seasons. For cowpea and mungbean no clear optimum growing periods were found.

The optimum growing periods shown in Fig. 76 were established in small, mainly hand-operated trial plots. Whether in practice mechanized farming can make use of these optimum periods depends on the workable time that is available for tillage operations, planting and harvesting in relation to the area cropped and the machine capacity available.

It is self-evident that the farmer will maximize the area under the most profitable crop, i.e. groundnut. It is probably advisable, however, to avoid continuous cropping of groundnut, although the results of the studies on this have not yet

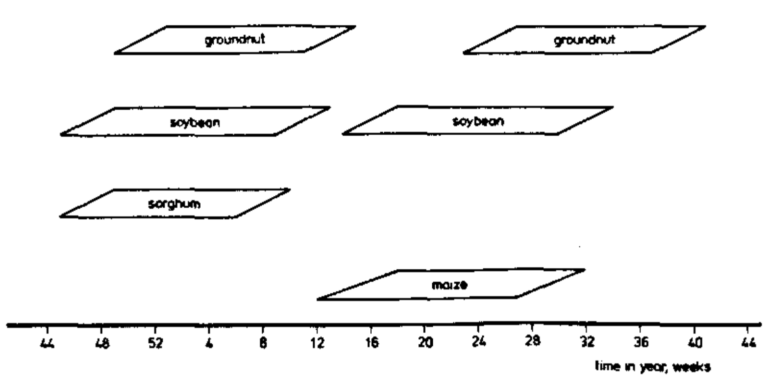


Fig. 76. Optimum growing seasons for six crops. The left and right oblique lines indicate the periods of planting and harvesting, respectively.

given conclusive answers (Section 6.7). It is also obvious that soybean, the second most economically attractive crop, is the first crop to consider for a rotation with groundnut. Since the time available for planting groundnut and soybean is limited, especially in April and June, it might be necessary also to grow crops that can be planted in other months. Table 95 suggests that sorghum would be such a crop. However, its optimum sowing time in the short rainy season is the same as that of soybean and the crop is susceptible to fungal diseases during ripening, therefore sorghum is not seen as a suitable crop in a rotation. If possible, during the short rainy season the entire area should be sown with groundnut and soybean. If this is not possible, cowpea and mungbean can be sown in the remaining area in January.

In April there is not much time for sowing. The time available after the harvesting of the short rainy season crops is very short. Sowing in May is practically out of the question because of the rains. This leaves March as the only sowing month and maize as the only crop to fall back on. Later, i.e. after June, cowpea and mungbean can be planted on the plots that then are still unoccupied. Although maize is not financially more attractive than cowpea and mungbean, it is preferred to these crops, because it has the advantage of leaving a substantial quantity of organic material on the soil, thus contributing to the maintenance of soil organic matter. Mungbean has lower production costs than cowpea, but because of its specific use, and hence the limited demand for it, the area planted to mungbean will in practice be smaller than the area planted to cowpea.

In conclusion, the order of attractiveness is groundnut, soybean, maize, cowpea and mungbean. A rotation scheme should be based as much as possible on groundnut and soybean, with the other crops used only to fill the gaps.

9.4 A farm-system design for the Zanderij soils

9.4.1 Cropping pattern and labour diagram

In this section an attempt is made to design a cropping pattern and labour diagram for a one-man farm on the Zanderij soils. At present, such a farm is hypothetical, and it seems almost pointless to design one, especially as most crops cannot be grown profitably (Table 95). But profits depend on price ratios; all crops studied would have a positive net balance if produce prices were 20 per cent higher and the costs remained the same as assumed in Table 93.

The most important motivation for designing such a farm is that it offers the opportunity of practically applying and integrating the results of the various experiments done during the project. In this way, such a hypothetical farm plan draws together all the findings of the project.

The following requirements and conditions were taken into account when designing the cropping pattern and labour diagram.

1 Four crops are grown in the most profitable way. The order of their profitability is: groundnut > soybean > maize > cowpea.

2 Sowing periods are: December and June for groundnut, November and April for soybean, mid-March to the end of April for maize and August to January for cowpea. Their growth cycles take 14, 16, 15 and 10 weeks, respectively.
3 The farm consists of parcels of 300 x 100 m, i.e. the same dimensions as used in Section 9.2.2 for the calculation of machine costs.
4 The same crop may not be grown on the same parcel for two consecutive seasons.
5 Workable hours for field operations are the average numbers shown in Figs. 67, 68 and 70. Workable hours for planting are equal to those for harrowing minus the time that it is too dry for ploughing. For fertilizer and biocide application only the upper moisture content limit of ploughing is restrictive. In the case of groundnut the workable hours for lifting are the same as those for ploughing.
6 The standard field operations are stubble mowing, ploughing, harrowing, planting, fertilizer application, spraying of herbicides, insecticides (for maize only) and fungicides (for groundnut only), second fertilizer application and harvesting.
7 The time interval between stubble mowing and ploughing should preferably not exceed one week. The same holds for the interval between ploughing and harrowing.
8 Harrowing, planting and fertilizer and herbicide application of a particular parcel should be done within the same week.
9 Lime is applied before the short rainy season, between stubble mowing and ploughing.
10 In peak labour periods the priority order of crops is: groundnut, soybean, maize, cowpea, and that of operations: harvesting, planting (including harrowing and fertilizer and herbicide application), ploughing, mowing and liming.
11 Labour peaks with more than 40 field hours per week should be avoided as much as possible; 50 hours per week forms the upper limit. In Weeks 51, 52 and 1, field work should be restricted to approximately 30 hours per week.

Time requirements were derived from Table 92 and standardized in hours per parcel as follows: mowing 4, liming 3, ploughing 10, combine harvesting 5. In Fig. 77, S stands for sowing, and includes harrowing, planting, fertilizer and herbicide application. Time requirements per parcel are 10 hours for maize, 11 for soybean and cowpea, and 13 for groundnut. Lifting of groundnut requires a little less than 6 hours and stripping a little more than 7 hours; usually these operations are carried out in the same week, requiring 13 hours per parcel.

The sequence of the planning of Fig. 77 was as follows. First the maximum number of parcels that can be planted to groundnut in December was calculated and next the number of parcels that can be planted to soybean in November. It was checked whether there was sufficient workable time in March and April to harvest these crops. Then it was calculated how many parcels can be planted to groundnut in June and to groundnut in April, again checking whether these

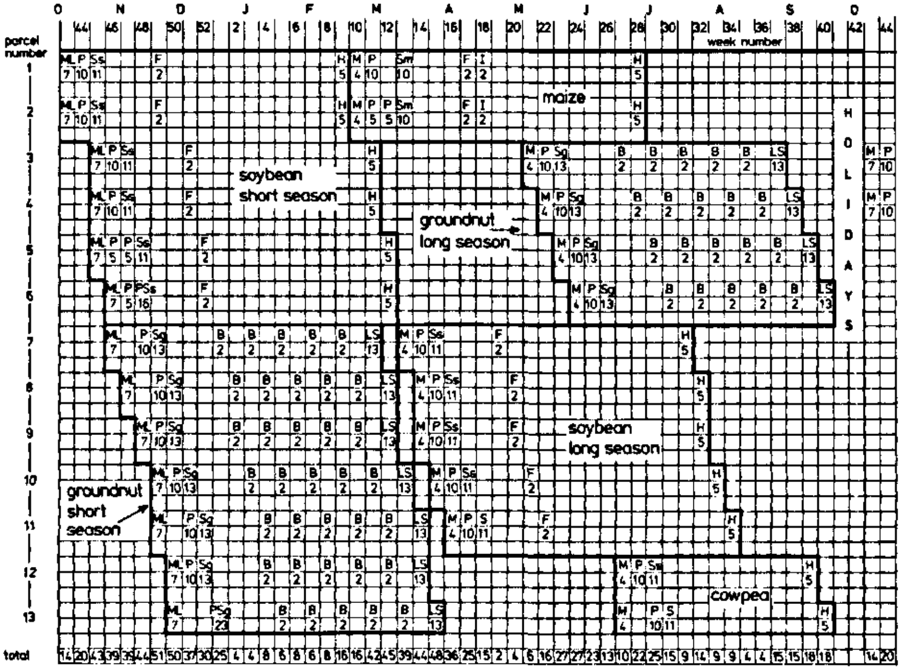


Fig. 77. Cropping pattern and labour diagram for a farm system on the Zanderij soils. M = mowing; L = liming; P = ploughing; Sc, Sg, Sm and Ss = sowing including harrowing, fertilizer and herbicide application for cowpea, groundnut, maize and soybean, respectively, F = second fertilizer application, I = insecticide application, B = biocide (fungicide) application, H = combine harvesting, LS = lifting and stripping of groundnuts. Numbers below the letters indicate the number of hours spent on that operation during a particular week.

crops can be harvested.

In December seven parcels can be planted to groundnut and in November six can be sown to soybean. It is possible to plant another parcel with soybean, but that would imply labour peaks of more than 50 hours per week during both planting and harvesting. Theoretically there is time available in January to plant cowpea. But this crop matures in March and April, and there is no time to harvest it. In June no more than four parcels can be sown to groundnut; the area is limited by the hours workable and the occurrence of labour peaks. Taking into account the time available for groundnut harvesting, the number of parcels that can be planted to soybean in April is limited to five. Thus, of the six parcels grown with soybean during the short rainy season, only four can be used for groundnut in the long rainy season. The remaining two parcels can be planted to maize in the second half of March. As not more than five parcels out of the seven grown with groundnut during the short rainy season can be used for soybean during the subsequent long rainy season, the remaining two have to be planted to cowpea. It then is too late to plant maize.

Fig. 77 shows that labour peaks occur in December and from mid-March to mid-April, and that labour pressure is low in January, February, May, mid-August to mid-September. Weeks 41 and 42, i.e. roughly between 5 and 20 October, can be made free for holidays.

In conclusion, workable time and labour peaks determine that the maximum number of cropped parcels for a one-man farm is 13, i.e. a total area of 39 ha.

Note that the scheme of Fig. 77 was based on average weather conditions and related numbers of workable hours. If it is not possible to plant soybean and groundnut as indicated in the scheme, the farmer can plant the remaining parcels to cowpea in January and August. If the weather is very favourable, more than four parcels can be planted to groundnut in June, at the expense of cowpea planned for August. Replacing soybean or maize by groundnut and maize by soybean will seldom be possible, because groundnut is planted later than soybean and maize, and soybean is planted later than maize.

9.4.2 Crop rotation

If the cropping pattern of Fig. 77 were repeated year after year the same crop would always be grown on the same parcel in the same season. Maize would be confined to Parcels 1 and 2, and cowpea to Parcels 12 and 13. This may not be desirable. Therefore, a rotation scheme was set up to overcome some of these specific problems.

Fig. 77 shows that in March maize can be planted only after the soybean that was planted in Week 45. Similarly, in Week 15 soybean can be planted only after the groundnut that was planted in Week 49 or perhaps 50. For cowpea and groundnut sown in the long rainy season there are no restrictions in this respect. In practice, the sequence of sowing will be as indicated in Fig. 77, and the combination of the short- and the long-season crops on a particular field can be considered as fixed. To facilitate the discussion, these crop combinations will henceforth be denoted by the codes shown in Fig. 78, where a scheme for two successive years is given. A complete rotation scheme comprises 13 years or 26 growing seasons. In the short rainy season each parcel is planted six times to soybean and seven times to groundnut, and in the long rainy season five times to soybean, four times to groundnut, twice to maize and twice to cowpea.

One of the prerequisites is that maize and cowpea are evenly distributed over the years. In Fig. 78 the crop combinations Ss1-Ml1, Ss2-Ml2, Ss3-Gl1 and Ss4-Gl2 move from Parcels 1-4 to Parcels 3-6. The combinations Ss5-Gl3 and Ss6-Gl4 cannot be transferred to Parcels 7 and 8, because here soybean is grown in the long rainy season of the first year. They can go either to Parcels 1 and 2 after maize, or to Parcels 12 and 13 after cowpea. The consequence of Ss5-Gl3 and Ss6-Gl4 after maize would be that in the short rainy season Parcels 1-6 are always planted to soybean and Parcels 7-13 to groundnut. Therefore Ss5-Gl3 and Ss6-Gl4 were not allocated to Parcels 1 and 2 but to Parcels 12 and 13 in the second year. The first-year combinations of these parcels, Gs6-Cl1 and Gs7-Cl2, cannot move to Parcels 1 and 2 in the second year, because cowpea

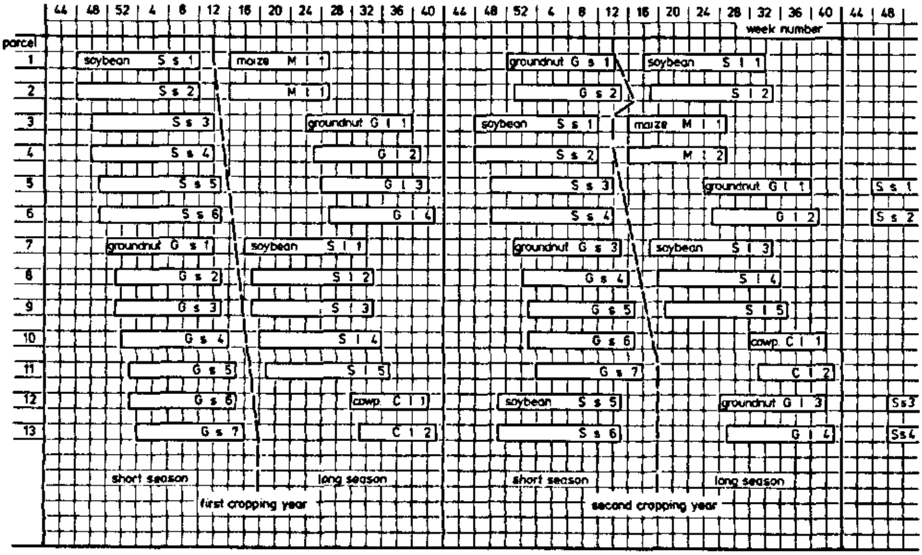


Fig. 78. Cropping pattern for two consecutive years. The first (capital) letters stand for soybean (S), groundnut (G), maize (M) and cowpea (C), and the second letter for short (s) and long (l) rainy season. The numbers refer to the sequence in which the parcels will be sown with the indicated crop in the indicated season.

year	1		2		3		4		5		6		7		8		9		10		11		12		13		1
season	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S
parcel																											
1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1
2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2
3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3
4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4
5	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5
6	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml2	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6
7	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Ss2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1
8	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Ss3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2
9	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Ss4	Gl6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3
10	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Ss5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4
11	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5
12	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6
13	Gs7	Cl2	Ss6	Gl4	Ss4	Gl2	Ss2	Ml2	Gs2	Sl2	Gs4	Sl4	Gs6	Cl1	Ss5	Gl3	Ss3	Gl1	Ss1	Ml1	Gs1	Sl1	Gs3	Sl3	Gs5	Sl5	Gs7
season	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S
year	1		2		3		4		5		6		7		8		9		10		11		12		13		1

Fig. 79. Proposed design for crop rotation of 13 years with 13 parcels. Letters and numbers have the same meaning as in Fig. 78.

after maize would be in conflict with the requirement of an even distribution of these crops over the years of the rotation. So, Gs6-Cl1 and Gs7-Cl2 go to Parcels 10 and 11, and similarly the first-year crops of Parcels 9, 10 and 11 move to Parcels 7, 8 and 9 in the second year. Finally, for Gs1-Sl1 and Gs2-Sl2 there is no choice other than Parcels 1 and 2 in the second year.

The complete rotation scheme for 13 years is shown in Fig. 79. Each parcel has exactly the same crop sequence, e.g. the sequence of Parcel 1 starts on Parcel 2 in Year 7, on Parcel 3 in Year 2, on Parcel 11 in Year 11. In this sequence, maize is grown in Years 1 and 8 and cowpea in Years 5 and 11 (Parcel 1) thus satisfying the requirement of an even distribution.

The main purpose of this excercise was to call attention to the peculiarities that are connected with designing a balanced crop rotation for a mechanized farm on the Zanderij soils. In practice many factors, especially weather conditions, will lead to deviations from such a scheme, making it even more difficult to follow a sound crop rotation.

10 General discussion and conclusions

In Section 1 the objectives of this project were described as follows:

1 to analyse the chemical, physical and biological changes taking place in and above the soil when rainforest is replaced by annual crops;
2 to identify the factors limiting the production of annual crops and to design methods to alleviate the constraints;
3 to indicate which crops are most promising and how they should be cultivated;
4 to find out what machinery would be most appropriate under the prevailing conditions;
5 to develop annual cropping systems within the framework of mechanized farming.

In this section the main research findings are summarized and conclusions that have implications for farming practice are drawn.

10.1 The change from forest to annual crops

Since the structural stability of the Zanderij soils is low and the soils are often wet because of the humid climate, clearing with heavy machinery easily leads to soil compaction. Windrowing can be particularly destructive.

To reduce soil damage, clearing should be done during the long dry season when the vegetation has used most of the soil moisture. But rain during this season is no exception and a heavy shower may call for an immediate halt to clearing operations until the soil is sufficiently dry again. After uprooting the trees, evapotranspiration is reduced and a long period of dry weather is required to dry out a bare soil. The best method is to allow the uprooted vegetation to dry, then to burn it, and to delay windrowing until the next long dry season, so that a living cover can be established in the ash-enriched soil. Such a cover will reduce runoff and erosion, keep some of the nutrients in circulation, promote water loss from the profile through transpiration and provide a better support for the tractor when it is piling the debris. This approach, however, results in an inefficient use of the heavy equipment and makes clearing very expensive. Contractors will not be interested. If land is to be cleared for agriculture the farmer or the agricultural development authority should be the owner of the equipment and should be the employer of the operators.

The risk of compaction might further be reduced by decreasing the distance between windrows, even though this initially leads to a less efficient use of the land. During the long dry seasons of subsequent years pairs of burnt windrows must be combined to give a new stack halfway between the former pair. This should be repeated until no debris remains to be burnt.

Immediately after clearing the land is not suitable for cultivation, because it is uneven and contains wood and roots that can interfere with mechanized field operations. The smaller depressions are filled with soil during windrowing, but not enough to level the field. Under regular tillage practices the situation gradually improves. In large-scale farming systematic levelling may be inevitable. The methods and the equipment to be used and their effect on soil fertility need further investigation.

At Kabo, the wood and roots that remained after clearing were removed by hand after passes with a heavy disc-harrow. It took many man-days and two years of regular cultivation before the plough layer was virtually free from such wood and root debris. For large areas mechanized methods must be developed to clear the plough layer from such debris.

The chemical fertility of the Zanderij soils is low and shows a very large variability. Upon clearing the variability increases, especially irregular burning leaves pockets of enrichments with phosphorus, potassium, calcium and magnesium. The cation exchange capacity of the soils is too low to retain the cations. Within a year the major part of the nutrients released (except phosphorus) has been lost by leaching. Soil tillage, fertilizer application and nutrient removal by the crops gradually reduce the heterogeneity in chemical fertility. The effects of former windrows, caused by accumulated topsoil and ash, last longer.

The soil and litter fauna present under forest virtually disappear upon mechanized clearing. Gradually another fauna is established under annual crops. Relationships between soil animal population and soil organic matter content were weak.

10.2 Factors limiting the production of annual crops

Climate

Theoretically, in the Zanderij area the highest dry-matter production would be obtained if crops were grown during the long dry season, because relative duration of sunshine in that season is high. This would require irrigation. Rainfed agriculture requires a reliable distribution of rainfall. Only the long dry season and the long rainy season are reliable as regards rainfall, but neither their beginning nor their end is predictable. This erratic rainfall pattern affects crop growth (because of drought periods) and workability for mechanized field operations (because of excessive wetness or dryness of the soil). It makes careful planning of farming operations difficult but essential, and requires analysis of long-term climatic data.

Soils

Once cleared for annual crop production, the soils of the Zanderij formation are susceptible to erosion, losing topsoil during periods of heavy rainfall. No erosion research was done, so no data are available on the slope characteristics at which the land can be safely used for annual crops. Erosion was not a problem in the project because the plots were small and the slopes were gentle. Erosion occurred locally, particularly shortly after planting, but no long-term effects were observed. When planning the layout of a farm or the position of windrows during clearing, erosion should nevertheless be taken into account; natural drainage systems should be maintained as much as possible and annual cropping should be restricted to the more or less level plateaus.

Frequent deep tillage is essential to keep the soil sufficiently loose and to incorporate lime and fertilizers in the top 25-30 cm of the soil, thus improving root distribution and reducing the crops' sensitivity to drought. The loosening effect usually does not last longer than one growing season. No tillage or minimum tillage were not successful. Irrespective of the method of tillage, a compacted soil layer develops between 20 and 40 to 50 cm depth. It can be removed by ploughing if it occurs within the first 25 cm. At greater depths subsoiling would be required, but its effect on crop yields has not been conclusive. As it has to be repeated to maintain its effects, it is not economic.

As roots hardly grow deeper than 30 cm and because of the light texture of the brown loams, moisture stress occurs after about five days without rain. This is one of the main reasons why sandier soils are unsuitable and only brown loams should be considered for annual crops. Moisture stress might appear, even during the long rainy season.

Crops differ in sensivity to drought. In order of decreasing sensitivity: maize, sorghum, soybean, groundnut, cowpea and mungbean. The position of cassava is somewhere between groundnut and cowpea. Planting at the optimum time is the best way to cope with the low water-holding capacity of the soils (Fig. 21 and Fig. 76).

After clearing, lime and fertilizers should be applied, first at relatively high rates to bring the soil to a so-called steady state level, and from then onwards at lower rates to compensate for the removal by crops and leaching. The steady state level is characterized by pH(H_2O) around 5.5, P-Bray-I 15 mg kg^{-1}, exchangeable K 0.7 mmol kg^{-1}, ionic equivalents of exchangeable Mg 2.0 mmol kg^{-1}. To reach this state, applications of two tonnes of lime, 150 kg P, 200 kg K and 50 kg Mg per year are required during two consecutive years.

After that, the annual applications per ha, i.e. for two crops, should be: one tonne of lime, 45 kg P, 180 kg K and 45 kg Mg for a crop rotation as outlined in Section 9.5.2 where groundnut and soybean each occupy about 40 per cent of the area cropped per year and maize and cowpea each occupy about 10 per cent of the area cropped per year. Of these crops only maize demands nitrogen fertilizer, which should be applied at a rate of 170 kg N per ha per season. To avoid any possible deficiency of micronutrients 25 kg FTE per ha can be applied every three years.

The yield levels that can be expected with these fertilizer dressings are 4.0, 2.5, 4.5 and 1.25 t ha^{-1} for groundnut, soybean, maize and cowpea, respectively, provided the crops are planted at the optimum time. Machine yields will be somewhat lower: 3.0, 2.25, 4.0 and 1.1 t ha^{-1}, respectively.

Pests and diseases

Insects known as pests for crops are not present in the forest, but their populations can build up quickly, because after clearing, the ecosystem is initially unstable because there is no control by predators or parasites.

The main pests were fall army worm and borers for the cereals, and leafhoppers and leaf feeding beetles for the grain legumes.

Groundnut is the most susceptible crop to diseases, especially to leaf spot and rust. Chemical control can prevent large reductions in yield. During wet conditions head blight and grain mould were common in sorghum, and leaf blight in maize.

Nematodes present in forest soil disappear upon clearing, problably as a joint result of microclimatic changes in the bare soil, burning, and the absence of host plants. Later, other nematode species can be imported via planting material and agricultural equipment.

At both Kabo and Coebiti, pests and diseases did not cause insurmountable problems. The two farms were isolated and occupied relatively small areas, and no crop was grown continuously in the field. Expanding the cultivated area could induce ecological changes and perhaps increase the pest and disease problems.

Weeds

Recently cleared areas are virtually free from herbaceous plants at first, but weeds soon colonize the field. Almost all weeds are introduced from elsewhere.

Weeds can significantly depress yields. Mechanical weed control is insufficient. Pre-emergence application of alachlor is recommended as standard practice, if necessary followed by a post-emergence application of atrazine. Noxious weed species require special attention. If the weed flora is regularly surveyed so that such weeds can be spotted at an early stage, they can still be exterminated with comparatively little effort.

10.3 Promising crops

A number of yield data pertaining to the crops that received most attention during this project are compared with yield data from elsewhere in Table 96. For maize, soybean, and sorghum and groundnut the project averages are respectively lower than, equal to, and higher than the world averages. The highest yields recorded in the project are 0.88, 0.76, 1.36 and 1.72 times the average of the best three world producers of maize, sorghum, soybean and groundnut, respectively. This confirms the conclusion of Section 9.2.3 that groundnut is the most promising crop for the Zanderij area, followed by soybean.

Low yields can partly be attributed to a wrong timing of planting. The average yield levels of the crops planted at the optimum time are generally approximately one-third higher than the overall averages, except for cowpea and mungbean which were little affected by planting time. The highest yields recorded are generally 1.6 times the average yields obtained for crops planted during the optimum

Table 96. Average yields (t ha^{-1}) by the best three world producers, world average and some project yield data for six crops.

	Maize	Sorghum	Soybean	Groundnut	Cowpea	Mungbean
World yields in 1981						
Best three[a,b])	7.3	5.5	3.3	3.2	n.d.[d])	n.d.
World average[a])	3.4	1.5	1.7	1.0	n.d.	n.d.
Project yields						
All trials[c])	2.8	2.0	1.7	2.5	1.0	0.8
At opt. planting date[c])	3.5	3.1	2.2	3.4	1.0	0.8
Highest recorded	6.4	4.2	4.5	5.5	1.6	1.4
Target	4.5	3.5	2.5	4.0	1.25	1.25
Machine yield	4.0	3.25	2.25	3.0	1.1	1.1

a) From FAO, 1982.
b) Data refer to Greece, Italy and USA for maize; Spain, Italy and Peru for sorghum; Yugoslavia, Italy and Canada for soybean; Israel, USA and Greece for groundnut.
c) Trials under standard cultivation practices.
d) n.d. = no data available.

period, indicating that other factors also played a role. These factors include tillage operations under too wet conditions, insufficient weed control and too low a pH. Below, other factors are discussed separately for the various crops.

Maize

The standard cultivation measures included a nitrogen application of 120 kg ha^{-1} and the highest yield was obtained with an application of 240 kg ha^{-1}. For the target yield of 4.5 t ha^{-1} an application of 170 kg ha^{-1} is recommended. The difference of 50 kg from the standard application corresponds with a yield difference of 50 x 0.4/25 = 0.8 t ha^{-1} (see Tables 32 and 34), bridging the major part of the gap between 3.5 (yield at optimum planting time) and 4.5 t ha^{-1}. Note that the same cultivars performed significantly better on sites of old windrows and on heavier textured soils in the coastal area, suggesting that soil properties play an important role. The generally thin stems, a rapidly deteriorating crop after flowering, the low ear weights and the many barren plants also point towards inadequate soil conditions. This also explains the often negative effect of high plant densities on yield, and may – at least in part – be held responsible for the high timeliness losses for harvesting during a wet period.

A concerted research effort will be necessary to determine the most limiting production factors. Until these factors are known, maize should not be grown beyond experimental scale. Once the limiting factors are known, an extensive programme should be started to screen cultivars for greater tolerance to the adverse conditions prevailing on the Zanderij soils. Lack of well-defined screening criteria might explain the disappointing results obtained in the variety trials.

Sorghum

The standard nitrogen application for sorghum was 100 kg ha^{-1} and the recommendation for the target yield is 2 x 70 kg. The difference of 40 kg N, corresponding with a yield difference of 40 x 0.4/25 = 0.64 t ha^{-1} is sufficient to explain the difference between the average yield at optimum planting time and the target yield (Table 96). Nevertheless, for the time being the prospects for sorghum are limited. The necessity of a reliable dry ripening and harvesting period to avoid infection with grain moulds confines sorghum to the short rainy season, but that season can better be used for growing groundnut and soybean.

The discouraging results obtained with sorghum are the reason why little has been done on varietal selection and fertilizing. Virtually all the work has been based on two cultivars only.

Soybean

The average yield of 1.7 t ha^{-1} includes low yields that have been almost invariably caused by drought during the podfilling stage. Planting in the long rainy season can avoid such problems but the unreliable dry weather at the end of this season may adversely affect ripening and harvesting. Soybean requires a good soil moisture supply until late in the growing season followed by dry weather for maturing and harvesting. The more or less gradual change from rainy to dry season and the soils' low water-holding capacity mean that such conditions hardly exist on the Zanderij soils. Cultivars with a longer growing cycle would better exploit the potential of the long rainy season.

Failures to establish a soybean crop are not uncommon. They can be ascribed to poor quality seed or to an unfavourable soil moisture regime at the time of planting. In the humid tropics good quality seed is difficult to obtain. Soybean seed readily and quickly loses its viability as a result of poor storage, a process that already starts during ripening if weather conditions are unfavourable. A soybean industry in Suriname may need a special seed production farm where soybean is planted late in the long rainy season using supplementary irrigation to maintain an adequate soil moisture supply until shortly before ripening.

As for the soil moisture regime at the time of planting, there is a very narrow range of soil moisture values in which germination and emergence are optimal. This means that the soil is soon too dry or too wet for soybean seed to germinate even if its quality is good . This may largely explain why the yield of soybean planted at the optimum time (November and April) is still relatively low. Its stringent soil moisture requirements make soybean an ideal crop for supplementary irrigation if fields of good quality seed are to be harvested.

No important pests or diseases have been observed, but this may change with time if larger areas are sown to soybean.

In conclusion, provided outlets can be found for its seeds or oil soybean might be a worthwhile crop for the Zanderij area.

Groundnut

Groundnut appears to be a promising crop for the loamy soils of the Zanderij formation. An erratic rainfall distribution during the growing season or some rain during harvesting normally has no disastrous effects. The crop tolerates drought very well and poses relatively few problems with harvesting.

Virtually all experience with groundnut, however, is based on the local cultivar Matjan. This cultivar, though well adapted, is not perfect. The ripe seeds have no dormancy period and germinate readily when the soil is moist. The cultivar is susceptible to rust and leaf spot diseases. Being early maturing, Matjan cannot make optimum use of the long rainy season. Quality aspects such as oil content and flavour were not criteria when selecting Matjan. The available US-manufactured harvesting equipment is designed for runner-type cultivars whereas Matjan is of the bunch type. Although there is enough room for improvement, these characteristics are not considered serious bottlenecks that would impede expansion of the groundnut area. Meanwhile, however, an intensification of its cultivation should be accompanied by a breeding and/or selection programme with emphasis on these characteristics. So far, no marked improvements have been recorded with introduced cultivars.

Provided the freshly harvested pods are dried to a moisture content about 0.08 – 0.09 and then stored under dry conditions, the quality of the planting material is not a problem. Groundnut has no specific plant nutritional requirements except for calcium, the presence of which in the soil is a must for podsetting and podfilling.

The leaf spot diseases and rust can be adequately controlled with fungicides and these control measures are economically justified.

In conclusion, large-scale groundnut production on the loamy soils of the Zanderij formation would be feasible and is worth further study. A proper rotation needs to be developed, although the possibility of monocropping, growing one crop a year, should not be excluded.

Cowpea

Cowpea is unlikely to become a crop that will be grown on large areas. In a humid climate cowpea production for its dry seeds is very risky, as a few consecutive rainy days with little sunshine can cause substantial losses in a ripening crop.

There are no important cultivation problems. Properly dried seed stored under dry conditions maintains its viability very well. So far no serious diseases or pests have been encountered.

The uneven ripening of cowpea poses special problems to combine harvesting, yielding greenish speckled seeds and thus an unacceptable product if some pods are still green or some green leaves are still present. The problem can be overcome by first mowing the crop into a swath and leaving it a few days in the field to dry before threshing it. This method requires a reliable dry period, and can therefore be used during the long dry season only. Whatever system is used, ehe harvested product as such is not marketable and needs further cleaning to remove stained, shrivelled and split seeds. Though important, post-harvest technology has not received any attention.

Mungbean

Mungbean has not received much attention. Like cowpea, with which the crop has much in common, it is considered a catch crop. Although it may serve this purpose better than cowpea, mungbean is not expected to be grown on large areas either. The average yield was lower than for cowpea but this is offset, at least locally, by a better price.

Mungbean seems less sturdy than cowpea. The much smaller seeds make the young fragile seedling more sensitive to damage, particularly when the primary leaves are affected. Also its root system is smaller and the crop is less tolerant to a low soil pH than cowpea.

Its more even ripening and the relative ease with which the dry pods of the local cultivar normally open suggest few problems with direct combine harvesting, but little evidence is available on this aspect. As with cowpea, a dry period is essential if a quality product is to be harvested.

Cassava

Its adaptation to acid, low fertility soils makes cassava a suitable crop for the Zanderij area. However, mechanization of cassava production being only partly possible, mechanized large-scale systems cannot yet be outlined. No machinery exists for the collecting and cutting of cassava stems to prepare planting material. Mechanized planting may be possible with modified sugar cane or tree planters whereas topdressing and the application of pesticides could be carried out by aircraft. Harvesting is still a problem. Machinery is available to lift the roots. The removal and the chopping up of the aboveground plant parts have not yet been solved.

It should be possible to find technical solutions to overcome the mechanization problems. It is doubtful whether a completely mechanized production system would be economically feasible. If the end product is cattle feed or cassava flour, which in Suriname's climate would require artificial drying, the cost price is likely to become prohibitive.

10.4 Appropriate machinery

Annual cropping in the Zanderij area is possible only if it is mechanized. It comprises the following operations and equipment.

Stubble mowing

Weeds and residues of the preceding crop hinder tillage operations and should therefore be rendered harmless. No special studies were carried out on stubble mowing. Standard mowers can be used. Workability problems are minimal; only during rains and as long as the stubble is very wet and the soil is saturated with moisture, should mowing be delayed.

Primary tillage
Of the various tillage treatments compared in the course of the project (disc ploughing, chisel ploughing, rotavating, disc harrowing and no tillage) disc ploughing turned out to be most satisfactory, resulting in the best incorporation of lime, fertilizers and weeds, and in the highest yields. On a soil free from wood debris, a mouldboard plough is to be preferred because it turns the soil better, resulting in a better control of weeds. Rotavating is not advised, because it damages the soil structure, the working depth is too shallow and weed control is poor. Direct seeding can be used once in a while to gain time when the sowing season is too short or when soil preparation is impossible because of workability problems.

The soil can be too dry (hard) or too wet for ploughing; the mass ratio of moisture to dry soil should be between 0.11 and 0.16.

Secondary tillage
Secondary tillage or seedbed preparation consists in harrowing to level and settle the soil. A power harrow, as used in the project, is not ideal since it pulverizes the soil too much. A spring-tine cultivator is possibly a better alternative, especially when used in combination with a roller to obtain the necessary soil settling. Which implements and methods can best be used needs further investigation.

Workability for harrowing is curtailed by too wet a soil; the mass ratio of moisture to dry soil must be below 0.15.

Planting
To avoid soil compaction all operations following ploughing should be combined as much as possible. In the project, planting and the first fertilizer application were carried out in the same operation. A four-row pneumatic precision planter equipped with flat vertical discs for seed metering and with special fertilizing attachments proved very satisfactory. For farmers a less complicated planter will be adequate. Row distance was 75 cm for maize, and 50 cm for sorghum, soybean, cowpea and mungbean. For groundnut alternate row distances of 35, 50, 35 and 80 cm were used (Fig. 60); this was not combined with fertilizer application.

The soil moisture range for planting is between 0.11 and 0.15 (mass ratio of moisture to dry soil) for a ploughed soil. Technically it is never too dry for planting, but seeds will not germinate in a dry soil. The criterion of a moisture mass ratio to dry soil of 0.11 is provisional.

Fertilizer and lime application
Lime was applied with a pendulum broadcaster, 6 m working width. Fertilizer spreaders with a larger working width should not be used unless the fields are sufficiently level, otherwise an even spread pattern will not be obtained. For side dressing of fertilizers a special attachment was mounted behind the broadcaster. The split fertilizer applications cause a problem for maize. Four and a half weeks after sowing the crop is too tall for standard low-clearance tractors.

The workability for fertilizer and lime application is the same as for harrowing.

Biocide application (spraying)
A tractor-mounted sprayer was used. No special problems were experienced. Workability is as for harrowing. This implies that during the long rainy season the soils are often too wet for the machinery to enter the field for fertilizer or pesticide application. With large areas the use of aircraft might be considered.

Harvesting of grain crops
Self-propelled combine harvesters can be used. For maize they should be equipped with a maize header, for soybean with a flexible cutter bar. Losses are related to moisture contents in grain and straw. Grain moisture content should be less than 0.28 for maize and less than 0.24 for the other crops, and soil moisture, expressed as mass ratio to dry soil, should be less than 0.16. Special problems with cowpea are discussed in Section 10.3.

Harvesting of groundnut
Groundnut harvesting entails two operations: lifting and stripping. For lifting (digging) the same workability criteria hold as for ploughing, i.e. a mass ratio of moisture to dry soil between 0.11 and 0.16. The pod moisture content at harvesting must be less than 0.45. For stripping, kernel moisture content must be less than 0.24, so the uprooted plants need some days to dry. Proper handling of the specific equipment requires experience, to avoid unnecessary losses during lifting.

Drying of harvested products
Artificial drying is a must for all harvested products. Bin drying, as used in Suriname for rice, can be applied. Drying time can be set at 48 hours and the bin surface at about 3 m^2 per tonne of grain and 3.5 m^2 per tonne of groundnut pods. No special studies were made on this topic.

10.5 Annual cropping systems

The research findings of this project refer to only a limited number of annual crops. Other economically more attractive or better adapted crops and cultivars may be possible. Moreover, the time was too short to provide sound, comprehensive answers to a complicated, long-term research problem like the one under study. The production factors are relatively expensive. In Suriname almost all inputs have to be imported and the quantities needed nationally are small. The most important cost item is liming materials and fertilizers. The machine capacity required per unit area is relatively large because of generally low numbers of workable hours, although this can largely be offset by growing two crops per year. Furthermore, artificial drying of all harvested produce is essential, to prevent rapid deterioration.

Comparison of the cost per hectare with world market prices for 1981 (Table 95) shows that groundnut and soybean are promising but that the cost of maize and sorghum is too high to be competitive. Though some improvement could still come from better and adapted cultivars and a more efficient utilization of inputs, the data suggest that for the time being only groundnut and soybean can form part of an annual cropping system. In that case part of the land remains uncropped during the long rainy season, because the number of workable hours in April is too low for both to harvest the short-season crops and to sow the long-season crops. In the example of a Zanderij farm, presented in Section 9.5, maize and cowpea were grown on the parcels that could not be planted to soybean or groundnut in the long rainy season. Green manure crops could be an alternative for maize and sorghum.

The one-man farm presented in Section 9.5 consists of 13 parcels of 3 ha each. In the short rainy season 6 parcels are planted to soybean and 7 to groundnut and in the long rainy season 5 to soybean, 4 to groundnut, 2 to maize and 2 to cowpea.

10.6 Final remarks

Mechanized farming with annual crops in a humid climate on acid infertile soils requires farmers of above-average quality. The farming systems considered are technologically advanced and are capital intensive. The climate-related workability problems make good timing and planning of the farming operations essential. A thorough knowledge of the climate, the soils and the crops to be grown is necessary to anticipate possible problems. Trained farmers and good support from an agricultural extension service are indispensible for the success of such farming.

From the results obtained it can be concluded that continuous annual cropping on the loamy soils of the Zanderij formation is technically possible but that high farm managerial skills are required if success is to be achieved. The technical research findings have been quantified where possible. In this way this Zanderij project should also be of value for areas outside Suriname with similar physical and environmental conditions. The feasibility of annual cropping might vary in such regions. As regards Suriname, groundnut and soybean show promise but the economic outlook for maize and sorghum is bleak. A systematic search should be initiated to identify crops that have better economic prospects and are better adapted to the environment. Upland rice and pineapple, which have been excluded so far, may well be worth considering. Production systems that combine annual crop production with cattle and grassland should be investigated.

No comparison was made between the financial returns from forest exploitation and those from annual cropping. It was not the aim of this project to ascertain whether it is advisable to convert the rainforest that presently covers the loamy Zanderij soils into arable land. To answer that question the ecological implications in terms of soil erosion and the risk of outbreaks of pests and diseases when large areas are continously cropped must also be taken into account.

Any decision on the use of low fertility acid soils such as those of the Zanderij area should be made in the national, social, economic and political context. If it is decided to use these soils for annual cropping, the selection of suitable farm sites should be based on soil survey data. Only the heavier soils can be considered, i.e. the brown loams with a loamy sand to sandy-loam topsoil (0-20 cm) on a sandy clay-loam subsoil. However, the often great variation in soil within short distances will make it difficult to find sufficiently large areas of a single type of soil, and pockets of lighter textured soils, such as brown or even white sands, cannot be completely avoided.

Although the brown loams as a rule are covered with high tropical rainforest, and less luxuriant types of vegetation are mostly indicative of soil types poorer than brown loams, vegetation type should not be used as an absolute criterion because high rainforest is sometimes underlain by brown sands. There is no need to select undisturbed rainforest. For practical purposes good secondary rainforest is adequate.

If cropping systems based on supplementary irrigation are considered, there should be a water source in the form of a well or stream that carries water, even at the end of the long dry season. This could mean that the northern part of the Zanderij belt, where the sand deposits are likely to be thicker, is to be preferred to the south. Much will also depend on the size of the catchment area feeding the streams concerned.

Clearing and the preparation of the land after clearing should be done by a development authority. Windrows have to be gradually reduced and cleared away, the fields need to be levelled, the soil has to be freed from wood and root debris and last but not least a plough layer with the desired (steady state) fertility level has to be developed. The preparations will take at least three years. Only completely prepared land suitable for annual crop production should be handed over to the farmer, to avoid discouragement and a possible untimely abandoning of fields.

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Appendices

1. Description and properties of a Coebiti soil profile.
2. Description and properties of a Kabo soil profile.
3. Lysimeter studies, March 1978 – May 1979.
4. Supplementary-irrigation trial at Coebiti.
5. Introduced varieties, cultivars, lines of maize, soybean, cowpea and mungbean, and collection of cassava clones.
6. Soil tillage, workability and timeliness of farm operations.
7. Methods of chemical soil and plant analysis.
8. Quantities and units.

Appendix 1. Description and properties of a Coebiti soil profile.

Location: Experimental Farm Coebiti, Suriname. Blok Al experiment 78/27 (Co 135), 31 m south-west of main road, 5 m north-west of Replication 4 (Profile 13).

Described by: R.L.H. Poels on 79.04.11

Site description
Elevation : approximately 20 m above sea level.
Physiographic position of the site: plateau.
Landform of surrounding area: level to undulating.
Topography: even.
Slope on which profile is sited: 2 per cent to the west.
Vegetation or land use: regrowth of low weeds after ploughing 6 months earlier, covering the soil for about 70 per cent.
Climate: tropical rainforest climate (Af) with 2 wet and 2 drier periods; average precipitation 2220 mm per year.
Parent material: 'Zanderij' sediment of sandy clay-loam texture.
Moisture condition: moist throughout.
Water table: not encountered.
Occurrence of gley/pseudogley: no.
External drainage: medium to slow.
Internal drainage: medium.
Drainage class: moderately well to well drained.
No surface stones or rock outcrops, no erosion, no salt or alkali.
Human interference: subsoiling in September 1978, 50 cm deep, 130 cm apart.

Brief description of the profile
Very deep, moderately well to well drained profile with a brown loamy-sand topsoil and dull brown to orange sandy-clay-loam subsoil. The B1 horizon (28-50 cm) is rather dense and roots are nearly absent below the A horizon. The effect of subsoiling, carried out 7 months before the description, on the profile is very slight. No differences in structure or colour are visible. The only effect is a slightly softer consistence of the soil in the subsoiled spots.

Classification: Ultic Haplortox.

Soil horizon description
0-16 cm A1p Brown (7.5YR 4/3) loamy sand; weak coarse and medium subangular blocky and fine crumb structure; very friable to

	loose when moist, non sticky and non plastic when wet; common fine and medium pores; common fine roots; clear smooth boundary.
16-28 cm A12	Brown (7.5YR 4/3) loamy sand; few fine faint brown mottles; moderate coarse and medium angular blocky structure; friable when moist, slightly sticky and non plastic when wet; few to common fine and medium pores; few fine roots; few pockets of subsoil material; few to common charcoal pieces; few small sandpockets; clear smooth boundary.
28-50 cm B1	Dull brown (7.5YR 5/4) sandy loam; weak to moderate coarse and medium angular and subangular blocky structure; friable when moist, slightly sticky and non plastic when wet; few fine pores; very few fine roots; in top of horizon common fine brown mottles, indicating slight periodic water stagnation; rather dense horizon; gradual smooth boundary.
50-70 cm B21	Orange (7.5YR 6/6) sandy clay-loam; weak coarse and medium angular and subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; few to common fine pores; no roots; few pockets with darker soil; diffuse smooth boundary.
70-100 cm B22	Yellow orange (7.5YR 7/8) sandy clay loam; weak coarse and medium subangular blocky structure; friable to very friable when moist, slightly sticky and slightly plastic when wet; few to common fine pores; sporadic fine roots; common vertical channels, diameter ca. 1 cm filled with dark soil.
100-200 cm C	Yellow orange (7.5YR 7/8) sandy clay-loam to sandy clay; friable to firm when moist.

Chemical properties

Depth cm	$pH(H_2O)$	pH(KCl)	C $g\ kg^{-1}$	N $g\ kg^{-1}$	C/N	P-Bray-I $mg\ kg^{-1}$
0- 16	4.4	3.8	20.5	1.4	15	0
16- 28	4.2	3.8	11.4	1.0	11	0
28- 50	4.9	4.1	5.1	–	–	0
50- 70	4.7	3.9	3.5	0.3	12	0
70-100	4.5	4.0	2.1	0.3	7	0
100-220	4.6	4.0	0.9	0.3	3	0

Depth cm	Exchangeable ionic equivalents, mmol kg^{-1} CEC	Ca	Mg	K	Na	Al	Bases	ECEC	Al/ECEC
0- 16	51.7	12.0	1.8	0.3	0.3	7.7	14.4	22.1	0.35
16- 28	32.4	2.3	0.4	0.1	0.1	9.7	2.9	12.6	0.77
28- 50	23.6	2.8	0.5	0.2	0.1	6.8	3.6	10.4	0.65
50- 70	19.4	1.3	0.3	0.1	0.2	6.5	1.9	8.4	0.77
70-100	14.5	1.2	0.3	0.1	0.1	4.0	1.6	5.6	0.71
100-220	15.0	0.5	0.2	0.1	0.2	4.4	1.0	5.4	0.81

Physical properties

Depth cm	Volume fraction of moisture at pF							Avail. moist.,mm	
	1	1.5	2	2.7	3.4	4.2	2-4.2	per hor.	cum.
0- 16	0.444	0.271	0.185	0.182	0.119	0.078	0.107	17.1	17.1
16- 28	0.408	0.299	0.222	0.214	0.133	0.100	0.122	14.6	31.7
28- 50	0.318	0.246	0.210	0.182	0.167	0.130	0.080	17.6	49.3
50- 70	0.355	0.263	0.216	0.187	0.172	0.147	0.069	13.8	63.1
70-100	0.350	0.257	0.198	0.159	0.157	0.125	0.073	21.9	85.0
100-220					0.210	0.178			

Depth cm	Bulk density Mg m^{-3}	Particle density Mg m^{-3}	Pore volume fraction	Volume fraction of air at pF 1	2
0- 16	1.24	2.57	0.518	0.074	0.333
16- 28	1.41	2.60	0.458	0.050	0.236
28- 50	1.62	2.63	0.384	0.066	0.174
50- 70	1.52	2.64	0.424	0.069	0.208
70-100	1.45	2.64	0.451	0.101	0.253

Appendix 2. Description and properties of a Kabo soil profile.

Location: Kabo area Suriname, project area, 214 m north of baseline, 27 m west of line 3 (Profile 3).

Described by: R.L.H. Poels on 78.01.11.

Site description

Elevation: approximately 35 m above sea level.
Physiographic position of the site: plain.
Landform of surrounding country: level to undulating.
Microtopography: even.
Slope on which profile is sited: 1-2 per cent.
Vegetation: High dryland forest, recently exploited for valuable timber (volume of extracted logs was about 25 m^3 ha^{-1}; extracted wood was predominantly Basralokus, Wana and Kopi); within radius of 17.84 m (1000 m^2 area) 9 trees with a d.b.h. of more than 40 cm (exploited trees included), having a total basal area of 3.5 m^2; species: 2 Basralokus (*Dicorynia guianensis*), 2 Gronfoeloe (*Qualea courulea*), 2 Sali (*Tetragastris* sp.), 1 Pikinmisiki (*Piptadenia suaveolens*), 1 Hooglandbaboen (*Virola melinonii*) and 1 Fomang (*Chaetocarpus schomburgkianus*); few to common lianas and strangling trees (*Clusia* sp. and *Ficus* sp.); undergrowth consists of common bugrumaka, 2-7 m high, and few paramaka palms (*Astrocaryum* spp.) and seedlings of trees and lianas; herbs and grasses practically absent.
Climate: tropical rainforest climate (Af) with 2 wet and 2 drier periods; average precipitation at Coebiti, 30 km to the east, is 2220 mm per year.
Parent material: 'Zanderij' sediment of medium coarse sandy clay-loam texture.
Moisture condition: moist throughout.
Water table: not encountered.
Occurrence of gley/pseudogley: not encountered.
External drainage: slow to medium.
Internal drainage: medium.
Drainage class: well to moderately well drained.
No surface stones or rock outcrops, no erosion, no salt or alkali, no human influence on soil profile.

Brief description of the profile

Very deep, well drained profile with a brown loamy-sand to sandy-loam topsoil and a bright yellowish brown sandy-clay-loam subsoil. Below 120 cm few faint orange mottles occur.

Classification: Ultic Haplortox.

Soil horizon description

0-8 cm A11	Brown (7.5YR 4/3) medium coarse loamy sand; moderate fine and medium crumb structure; very friable when moist, non sticky and non plastic when wet; common very fine interstitial pores; abundant fine and medium, common large roots, forming a rootmat; thin layer of leaves and twigs 1 cm thick; common pockets of loose sandy grains; few bleached sand grains; gradual smooth boundary
8-17 cm A12	Brown (7.5YR 4/3) sandy loam; moderate medium and coarse subangular blocky and fine crumb structure; very friable when moist, slightly sticky and non plastic when wet; common very fine interstitial pores; many fine and medium, common large roots; common small sand pockets; gradual smooth boundary.
17-37 cm A3	Dull yellowisch brown (10YR 5/4) sandy clay-loam; weak coarse subangular blocky structure; friable when moist, sticky and plastic when wet; many very fine interstitial, few fine tubular pores; many fine and medium, common large roots and few dead fine roots; slightly variable colour indicating possible periodic wetness; gradual smooth boundary.
37-51 cm B1	Dull yellow orange (10YR 7/4) sandy clay-loam; very weak coarse subangular blocky structure, subdivided into fine granules; friable when moist, sticky and plastic when wet; common very fine interstitial pores; common fine, medium and large roots; diffuse smooth boundary.
51-120 cm B21	Bright yellowish brown (10YR 7/6) sandy clay-loam; very weak coarse prismatic and subangular blocky structure, subdivided into fine granules; friable when moist, sticky and plastic when wet; common very fine interstitial, few fine tubular pores; few fine, medium and large roots; no cutans; diffuse smooth boundary.
120-200 cm B22	Bright yellowish brown (10YR 6/6) sandy clay-loam; few coarse sand grains; few medium faint orange (5 YR 6/8) mottles; very weak coarse prismatic and subangular blocky structure, subdivided into fine granules; friable when moist, sticky and plastic when wet; common very fine interstitial, few fine tubular pores; few fine and medium roots; slightly variable colour possibly indicating periodic wetness.
200-280 cm B3	Yellow orange (7.5YR 7/8) sandy clay-loam; few coarse sand grains; no mottles; few roots.

Chemical properties

Depth cm	$pH(H_2O)$	pH(KCl)	C $g\,kg^{-1}$	N $g\,kg^{-1}$	C/N	P-Bray-I $mg\,kg^{-1}$
0- 8	3.9	3.1	16.3	1.0	16	2.6
8- 17	4.0	3.5	13.1	1.0	13	1.9
17- 37	4.3	3.8	8.0	0.6	13	2.9
37- 51	4.1	3.9	4.1	0.3	14	0.6
51-120	4.7	3.9	2.1	0.3	7	1.1
120-180	4.8	4.1	0.9	0.2	5	0.0
200-280	4.5	4.1	0.3	0.2	2	0.0

Depth	Exchangeable ionic equivalents, $mmol\,kg^{-1}$								
cm	CEC	Ca	Mg	K	Na	Al	Bases	ECEC	Al/ECEC
0- 8	53.3	3.3	1.8	0.7	0.5	9.0	6.3	15.3	0.59
8- 17	34.8	0.0	0.4	0.4	0.5	11.4	1.3	12.7	0.90
17- 37	27.8	0.0	0.2	0.3	0.4	9.8	0.9	10.7	0.92
37- 51	16.8	0.0	0.1	0.1	0.2	6.5	0.4	6.9	0.94
51-120	15.2	0.0	0.1	0.1	0.4	5.9	0.6	6.5	0.91
120-180	14.4	0.0	0.1	0.1	0.0	4.1	0.2	4.3	0.95
200-280	10.5	0.0	0.0	0.1	0.0	0.0	0.1	3.5	0.97

Physical properties

Depth cm	Volume fraction of moisture at pF						Avail. moist.,mm	
	1.0	2.0	2.7	3.5	4.2	2-4.2	per hor.	cum.
0- 8	0.365	0.154	0.099	0.091	0.074	0.080	6.4	6.4
8- 17	0.370	0.181	0.128	0.099	0.079	0.102	9.2	15.6
17- 37	0.364	0.203	0.152	0.132	0.104	0.099	19.8	35.4
37- 51	0.332	0.186	0.138	0.117	0.099	0.087	12.2	47.6
51-120	0.348	0.199	0.148	0.124	0.112	0.087	60.0	107.6
120-180	0.342	0.219	0.168	0.132	0.133	0.086	51.6	159.2

Depth cm	Bulk density $Mg\,m^{-3}$	Pore volume	Volume fraction of air at pF		Sand $g\,kg^{-1}$	Silt $g\,kg^{-1}$	Clay $g\,kg^{-1}$	Penetro-meter MPa
			1	2				
0- 8	1.23	0.523	0.158	0.369	844	61	95	0.04
8- 17	1.30	0.498	0.128	0.317	799	80	121	0.12
17- 37	1.45	0.458	0.094	0.255	764	43	193	0.25
37- 51	1.48	0.437	0.105	0.251	764	33	203	0.21
51-120	1.38	0.477	0.129	0.278	717	33	250	0.32
120-180	1.45	0.453	0.111	0.234	699	39	262	0.35
200-280					743	19	238	

Appendix 3. Lysimeter studies, March 1978 - May 1979.

Precipitation (P), irrigation (I), drainage (D), evapotranspiration of the lysimeter (E_L), and evaporation of the Class-A pan (E_0(A)). All data are expressed in mm per ten days. For explanation see Section 6.2.1.

Crop	Period		P	I	D	E_L	E_0(A)	E_L/E_0(A)
Maize	March	1-10	5	89	33	22	52	0.4
		11-20	12	12	17	18	53	0.4
		21-31	31	0	6	16	58	0.3
	April	1-10	29	0	7	24	46	0.5
		11-20	69	0	18	39	48	0.8
		21-30	104	0	57	46	49	0.9
	May	1-10	78	0	14	49	39	1.3
		11-20	73	0	31	42	32	1.3
		21-31	187	0	131	40	33	1.2
	June	1-10	69	0	28	43	38	1.1
		11-20	85	0	33	36	38	1.0
		21-30	65	0	38	30	36	0.8
Soybean	November	1-10	32	4	13	10	49	0.2
		11-20	27	0	12	17	37	0.5
		21-30	17	4	5	15	50	0.3
	December	1-10	120	0	53	28	30	0.9
		11-20	30	0	44	33	34	1.0
		21-31	135	0	68	51	50	1.0
	January	1-10	50	0	53	34	32	1.1
		11-20	16	0	0	56	50	1.1
		21-31	73	0	0	37	34	1.1
	February	1-10	1	0	0	40	51	0.8
		11-20	1	0	0	27	51	0.5
Cowpea	March	1-10	50	0	0	8	35	0.2
		11-20	32	0	0	18	35	0.5
		21-31	48	0	0	16	49	0.3
	April	1-10	151	0	88	36	29	1.2
		11-20	69	0	43	51	39	1.3
		21-30	79	0	0	54	35	1.6
	May	1-10	50	0	38	86	55	1.6
		11-20	30	0	0	41	36	1.2

Appendix 4. Supplementary-irrigation trial at Coebiti.

Rainfall, irrigation, and Class-A evaporation (E_0(A)) in mm per week. WAP = weeks after planting of the first crop in that cycle. No data were available on E_0(A) during the first cycle; the values presented in parentheses are averages of E_0(A) measured in the corresponding weeks in 1980, 1981, 1982 and 1983.

WAP	Rainfall	Irrigation	E_0(A)	WAP	Rainfall	Irrigation	E_0(A)
Cycle 1.	Maize, 79.10.17-80.02.05 Soybean, 79.10.16-80.01.27						
1	26	8	(41)	9	24	0	(24)
2	0	0	(37)	10	28	20	(25)
3	14	32	(39)	11	16	0	(19)
4	82	16	(35)	12	20	40	(23)
5	8	0	(32)	13	0	20	(22)
6	56	24	(32)	14	12	0	(27)
7	60	0	(30)	15	4	0	(27)
8	108	0	(29)	16	14	0	(25)
Cycle 2.	Maize, 80.02.20-80.06.10 Soybean, 80.03.06-80.06.17						
1	0	0	24	9	88	0	21
2	0	12	26	10	92	0	18
3	46	18[1)]	28	11	88	0	21
4	50	0	23	12	56	0	19
5	36	0	19	13	32	0	20
6	48	0	23	14	92	0	25
7	24	0	38	15	78	0	22
8	65	0	17	16	44	0	22
Cycle 3.	Maize, 80.08.07-80.11.27 Soybean, 80.08.14-80.12.04						
1	22	0	31	9	2	44	44
2	36	0	34	10	44	36	27
3	4	0	40	11	18	16	31
4	62	0	34	12	16	0	32
5	12	0	40	13	0	14	44
6	2	14	34	14	72	28	38
7	0	32	46	15	70	0	23
8	14	66	45	16	48	0	25

WAP	Rainfall	Irrigation	E_0(A)	WAP	Rainfall	Irrigation	E_0(A)
Cycle 4.	Maize, 81.01.08-81.05.09 Soybean, 81.01.08-81.05.01						
1	14	0	27	9	42	0	27
2	12	0	29	10	0	0	39
3	0	6	28	11	0	42	42
4	16	0	24	12	8	42	40
5	44	12	20	13	44	44	34
6	70	0	19	14	94	0	20
7	84	0	24	15	52	0	28
8	88	0	19	16	48	0	25
Cycle 5.	Maize, 81.10.27-82.02.16 Sorghum, 81.10.27-82.01.26						
1	0	9[1])	37	9	8	0	28
2	15	0	35	10	26	0	24
3	24	0	34	11	80	0	18
4	12	0	31	12	32	0	28
5	6	0	27	13	40	0	21
6	14	14	28	14	45	0	27
7	40	0	24	15	36	0	19
8	30	0	22	16	12	0	25
Cycle 6.	Soybean, 82.06.30-82.10.22 Groundnut, 82.06.30-82.10.05						
1	76	0	25	9	6	0	36
2	41	0	25	10	7	0	40
3	68	0	39	11	1	0	44
4	67	0	32	12	28	0	43
5	28	0	32	13	52	0	37
6	50	0	32	14	27	0	33
7	23	0	34	15	19	0	40
8	10	0	36	16	1	0	46
Cycle 7.	Maize, 82.11.11-82.02.23						
1	14	0	42	9	85	0	14
2	24	0	36	10	22	0	20
3	12	0	28	11	6	28	27
4	0	0	42	12	1	32	32
5	50	0	25	13	21	12	21
6	78	0	24	14	0	0	31
7	42	0	16	15	49	0	17
8	13	0	29				

[1]) The entire field, i.e. both irrigated and rainfed plots, received this amount of irrigation water. See Section 6.2.2.

Appendix 5. Introduced varieties, cultivars, lines of maize, soybean, cowpea and mungbean, and collection of cassava clones.

A. **Maize.** Open-pollinated varieties introduced in the period 1978-1980.

From CIMMYT, Mexico

Tuxpeño	Poza Rica 7528
Mezcla Tropical Blanca	Poza Rica 7824
Blanco Cristal 1	San Andres 7528
(Mix. 1 x Col. Gpo 1) ETO	Ludhiana 7528
Mezcla Amarilla	Across 7726
Amarillo Dentado 2	Across 7728
Amarillo Cristal	Sete Lagoas 7728
Tuxpeño Caribe 1	La Maquina 7827
Tuxpeño Caribe 2	Pool 25
Cogollero	Pool 26
Cotaxtla 7429	

From CNPMS, Brazil

CMS 04	CMS 014

B. **Soybean.** Cultivars and lines introduced in the period 1977-1980.

From INTSOY/IITA, Nigeria

Bossier	TGm 210-1-2317
B-1	TGm 210-1-2363
Cobb	TGm 242-2-2297
Davis	TGm 249-3
Improved Pelican	TGm 249-4
Williams	TGm 249-5-4254
Forrest	TGm 249-5-5078
Jupiter	TGm 255-2-4341
Amsoy 4192	TGm 260-2-2-4293
TGm 187-3-2	TGm 294-4-2371
TGm 197-3-3-2494	TGx 13-3-2644
TGm 210-1-2205	TGx 66-5100

From AVRDC, Taiwan

30066-2-4	30120-2-118
30098-4	30120-38-53
30103-62	30122-1-4
30106-2-27	30156-7
30120-38-76	30156-9
30120-46-88	30156-18
30153-1-96	30159-54
30155-12-53	30164-55
30164-52	30217-18-67
30299-6	30229-8
30295-17-74	30229-12
30120-2-78	30251-1-6

From INTSOY, USA

F 76-8827	Acc 2120
ICA L-215	Turnia
IGH 24	Alamo
V-1	UFV-1 (BP-2)
IGH 23	SJ-2
Caribe	Hutton

From INPA, Brazil

Ajuricaba	Solimoes
Manaus	

C. **Cowpea.** Cultivars and lines introduced in the period 1972-1981.

From Agricultural Experiment Station, Paramaribo, Suriname

Capucijner 5403A	Acc. 73026
Capucijner 6101	Acc. 73027
Blackeye	Acc. 73030
African Red	Acc. 73031
Acc 73021	Acc. 73032

From USDA, Beltsville, USA

PI 124609	PI 293477
PI 165486	PI 293497

From IRAT, Senegal

5/8-40 – 1/4-66-74, 1/8-50 L.4	185 x 40 – 3/4-40 L.9
5/8-40 – 1/4-66-74, 1/8-50 L.19	

From Kano, Nigeria

Acc. 593	Blackeye 8152
Kwarra	Acc. 6017

From IITA, Nigeria

TVu 157-1E	TVx 1576-01E
TVu 201-1D	TVx 1836-9E
TVu 1190E-1D	TVx 1836-013J
TVu 1502-1C	TVx 1836-015J
TVu 1630	TVx 1836-19E
TVu 1977-OD	TVx 1836P-19E
TVu 1987-01B	TVx 1836-66E
TVu 2616 P-01D	TVx 1836-90E
TVu 3629	TVx 1836-150G
TVu 4557	TVx 1836-157G
TVx 6-4H	TVx 1836-429E
TVx 7-4K	TVx 1836-473E
TVx 7-5H	TVx 1843-1C
TVx 12-01E	TVx 2112-6E
TVx 13-2E	TVx 2251
TVx 13-31K	TVx 2394-01F
TVx 14-5H	TVx 2394-02F
TVx 30-1G	TVx 2724-01F
TVx 33-1G	TVx 2869-P_2-2
TVx 66-2H	TVx 3072-01E
TVx 289-4G	TVx 3404-012E
TVx 309-1G	TVx 3428-03E
TVx 337-3F	4R-267-1F
TVx 876-01A	SVS-3
TVx 930-01B	Vita 1
TVx 944-02E	Vita 2
TVx 966-01B	Vita 3
TVx 1193-7D	Vita 4
TVx 1193-9F	Vita 5
TVx 1193-059D	

D. **Mungbean.** Cultivars introduced from AVRDC, Taiwan, in 1978.

Berker PARC	ML-3
BPI glabrous 3	ML-5
CES 1D-21	ML-28
KJ 5	MG 15-2
Local CV	MG 50-10A (G)
M 7A	MG 50-10A (Y)
M 163	Oklahoma 12
TM 304	PHLV 18
M 317	Taiwan I
M 1712	Vang Lang Khank

E. **Cassava.** Collection of clones. 1974.

From Agricultural Experiment Station, Paramaribo, Suriname.

Zoet 2	Kankantrie
Zoet 3	Basiorao
Bitter 3	Betawi
Bitter 5	Mangi
Bitter 6	Miss Jane (licht)
Bitter I	Miss Jane (donker)
Bitter II	Sao Pedro Preto
Bitter III	Soponjono
Bitter IV	Indische Stok
Bitter V	

From Instituto de Agronomia, Universidad Central de Venezuela, Maracay.

2062	2184
2078	2188
2106	2195
2124	2203
2171	2219

From Instituto Agronomico, Campinas, São Paulo, Brazil.

797 Ouro do Vale	IAC-24-2 Mantiqueira
454 Guaxupe	

From ICA, Palmira, Colombia

Llanera CMC no. 9

Appendix 6. Soil tillage, workability and timeliness of farm operations.

The following is the author's summary of:
'Mechanized farming in the humid tropics with special reference to soil tillage, workability and timeliness of farm operations. A case study for the Zanderij area of Suriname' (Goense, 1987).

The reported investigations concern aspects of mechanized farming for the production of rainfed crops on the loamy soils of the Zanderij formation in Suriname and in particular, the effect of tillage on crop yield and soil properties, workability of field operations and timeliness of field operations. The results were evaluated as to their effect on prospects for mechanized farming in this area.

The work was carried out within a joint research project of the Agricultural University Wageningen and the University of Suriname.

The soil in the area of investigation is characterized by a low fertility and high acidity. Natural drainage is good but the water holding capacity is low. The climate in the area is classified as Af according to Köppen, the average rainfall is 2234 mm per year.

Experiments carried out on the Coebiti experimental farm during a 9-year period, covering 22 cropping cycles, showed that with continued application of conventional tillage consisting of disc ploughing and harrowing, average crop yields were higher than with successive applications of shallow or no tillage. The yield differences varied with crop and conditions, the yield obtained under no tillage was on average about 75 per cent of the yield under conventional tillage for maize, sorghum and cowpea. For soya bean this was 85 per cent and for groundnuts 90 per cent. Shallow tillage like rotavating showed intermediate results. Comparable results were obtained at the Kabo experimental farm covering 4 cropping cycles. Chisel and disc ploughing showed here little difference. With the applied mechanized farming system soil compaction occurs which can be alleviated by soil tillage. The distribution of added fertilizer in the soil reflects the tillage treatments applied. Periodic deep tillage such as ploughing is required to incorporate lime to the appropriate depth to allow deep rooting. From a series of 6 cropping cycles at Coebiti it is concluded that the yield of a no tillage treatment when alternated with conventional tillage can be higher than those obtained under successive application of no tillage. This indicates possibilities for the application of incidental no tillage when workable time for planting is limited. It is concluded that in a mechanized cropping system on these soils, the approach to soil tillage should be flexible. Disc or chisel ploughing, as well as shallow or no tillage can be selected appropriate to crop and prevailing circumstances of field, weather and work progress.

The limits for workability of disc ploughing and harrowing were determined by measuring the performance of the operations and relating the results to the moisture content of the 0.0-0.20 m soil layer. The maximum soil moisture content for disc ploughing was found to be 13.9 per cent wb and for rotary harrowing 13.2 per cent wb. It appeared to be too dry for disc ploughing when the moisture content was lower than 10.3 per cent wb.

The measured soil moisture contents and pertaining meteorological data were used in development of a soil moisture model formulated with physical process descriptions from literature. Expectations of workable time for field operations in so far as limited by rain and soil moisture content were calculated with the model on the basis of a 25-year record of meteorological data at Zanderij station.

Workability of grain harvesting is governed by the grain moisture status. In field experiments the course of the grain moisture content and attached moisture was determined for maize, groundnut, soya bean, cowpea and sorghum. A practical grain moisture model to calculate the grain moisture status in dependence of the weather was formulated and developed with the experimental data and pertaining meteorological data. The hourly course of grain moisture status after maturity was calculated for the 25-year period, allowing calculations of expectations of workable time for harvesting operations with the appropriate limits for grain moisture content.

The timeliness function for maize planting was calculated with an available model of physical crop production (WOFOST). Available data from maize growing experiments in the area were used for calculating site specific parameters and evaluation of the model. With this model yield expectations were calculated on the basis of the 25-year meteorological record.

Harvest-date experiments were carried out to establish timeliness functions for harvesting of maize, groundnut, soya bean and sorghum. It appeared that crop stand and weather influenced these functions. For maize timeliness costs of up to 100 kg per day were observed under wet conditions in the initial delay period. Under dry conditions timeliness costs were insignificant for the periods considered. For a healthy groundnut crop timeliness costs could be presented by a quadratic function of delay time. Postponement of digging results initially in minor yield reductions per day, the losses per day in the windrow are about four times as high. On a diseased crop losses were much higher. For sorghum observed timeliness costs were between 1.0 and 1.9 per cent of initial machine yield per day of postponement of harvesting beyond the date of maturity. The timeliness costs for soya bean harvesting were small in the first two weeks after maturity and increased sharply with further delay.

The effect of the results of the investigations on the prospects for mechanized farming in the Zanderij area was evaluated with a linear programming model. The evaluation was done for a farm for the cultivation of maize and groundnuts. This farm, equipped with machinery matching a 55-kW tractor, was operated by the farmer on his own except for harvesting operations. Maximization showed that with p-20 values for workable time an area of 35 ha can be cultivated with a cropping index of 1.9. Workable time is limiting farm operations at opportune times and no tillage planting for maize has to be applied for the long rainy season.

The timeliness costs of harvesting had only small effect on the cropping plan. With p-50 values for workable time a cropping index of 2.5 is obtained in the maximization, in this situation workable time is not limiting farm operations and the option for no tillage is not used.

Workable time is a limiting factor for mechanized farming in the Zanderij area and quantified information is essential for planning. The evaluation provides sufficient indications for strategies to follow to make a mechanized farming system practicable.

It is concluded that the model type farm is a practicable proposition, provided socio-economic circumstances allow. A high standard of management is required for the proper planning and timing of the field operations.

Appendix 7. Methods of chemical soil and plant analysis.

Soil

C	Oxidation with potassium dichromate and sulphuric acid (Walkley-Black method). Total organic C = 1.15 x C(Walkley-Black). Soil organic matter = 1.75 x total organic C.
Total N	Titrimetrically after digestion with sulphuric acid plus salicylic acid plus Se and distillation in micro distillation unit.
pH(KCl)	Potentiometrically in suspension (1:2.5) with 1M potassium chloride.
pH(H_2O)	Ditto, with water.
K, Ca and Mg	Determined with atomic absorption spectrophotometer in 1M ammonium-acetate percolate (pH7).
Al	Colorimetrically in percolate of 1M potassium chloride.
CEC	Percolation with 1M ammonium acetate (pH7) followed by determination of ammonium replaced by calcium chloride and hydrochloric acid.
ECEC	Calculated as exchangeable K + Mg + Ca (as determined in NH_4 acetate) plus exchangeable Al (as determined in 1M KCl) + 0.01 (or 0.02). (0.01 or 0.02 is the estimated content of exchangeable Na (mmol/kg). This procedure was followed because Na was seldom determined in our laboratory).
P-Bray-I	Colorimetrically (molybdenum blue) in extract of 0.03M ammonium fluoride and 0.025M hydrochloric acid (Bray-I solution).
Total P	Colorimetrically (molybdenum blue) after digestion with Fleischmann's acid (equal volumes of concentrated H_2SO_4 and concentrated HNO_3).

Plant

Digestion	Wet digestion with concentrated sulphuric acid plus salicylic acid, and hydrogen peroxide; after digestion 1:20 diluted (Solution A).
Total N	Titrimetrically after distillation of aliquot of Solution A in micro distillation unit.
P	Colorimetrically (molybdenum blue) in Solution A.
K, Ca and Mg	Determined with atomic absorption spectrophotometer in Solution A.

Appendix 8. Quantities and units.

Soil data

Exchangeable cations and cation exchange capacity (CEC) are expressed in mmol ionic equivalents per kg dry soil. One mmol ionic equivalents of species X is the amount of substance of species X that is equivalent to one mmol of H^+ in an exchange reaction. Thus, the unit ionic equivalent equals the formerly used unit of a milli-equivalent. Example: 1 mmol ionic equivalent Ca^{2+} = 1 mmol 0.5 Ca^{2+} = 0.5 mmol Ca^{2+} = 1 meq Ca^{2+}.

Organic N and organic C are expressed in g per kg dry soil.

P-Bray-I and total P are expressed in mg per kg dry soil, i.e. in mg of the element, not the oxide P_2O_5.

Volumic mass or bulk density is the ratio of dry soil mass to soil volume; it is expressed in Mg m^{-3} or in kg dm^{-3}.

Soil moisture content is expressed either as the mass ratio of moisture to dry soil, or as the volume fraction of soil. In the text it is always indicated which units are used.

Soil moisture tension (tensiometer value) is the sum of matric and osmotic potential of soil moisture; it is expressed in kPa (1 kPa $\approx$ 0.0102 kg cm^{-2} and 1 kPa = 10 mbar).

pF is the logarithm of the negative pressure head (of soil moisture) in centimetres of water; so, pF 2 corresponds with a 10^2 cm water column or with 9.80665 kPa.

Soil texture is the size distribution of mineral soil particles; it is expressed in per cent or in g per kg of dry mineral soil (= soil without organic matter).

Penetrometer resistance is the pressure required to push a penetrometer with a conus area of 1 cm^2 in the soil; it is expressed in MPa (1 MPa $\approx$ 10.2 kg cm^{-2}).

Crops and agricultural practices

Yields of grains refer to grains with a moisture content of 0.12. Yields are expressed in kg ha^{-1} or in t ha^{-1} (t = tonnes). Groundnut yields refer to pod yields (moisture content 0.12), unless stated otherwise. Yields of cassava and sweet potato refer to fresh roots and tubers, respectively.

Moisture content of grains: mass ratio of moisture to 'moist' product.

Nutrient content in plant components: mass ratio of nutrient (element) to dry plant component (dried at 70°C).

Nutrient uptake is the quantity of nutrients in the above-ground plant parts; expressed in kg element per ha per season.

Fertilizer nutrient rates are expressed in kg of element (not oxides) per ha per season.

Biocide application rates are expressed in kg of active ingredient (a.i.) per ha, in kg of wettable powder (w.p.) per ha, or in litres of emulsifiable concentrate (e.c.) per ha.

Meteorological data

Relative duration of sunshine: ratio of the recorded sunshine hours to the 10 hours between 07.00 and 17.00 h.

E_0 is open-water evaporation expressed in mm per time unit.

E_0A is Class-A pan evaporation expressed in mm per time unit.

E_L is evapotranspiration measured with lysimeter expressed in mm per time unit.