Competition between crops and weeds in the Zanderij area of Suriname

Promotoren:

dr.ir. J.D. Ferwerda
emeritus hoogleraar in de Tropische Landbouwplantenteelt

dr. P. Zonderwijk
emeritus hoogleraar in de Vegetatiekunde en Plantenoecologie en de Onkruidkunde

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A.P. Everaarts

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STELLINGEN

1

Voor een goed inzicht in de onkruidgroei in op rijen gezaaide gewassen is een afzonderlijke bemonstering van de onkruiden in en tussen de rijen noodzakelijk.

M.C. Klay, 1983. Analysis and evaluation of tillage on an Alfisol in a semi-arid tropical region of India. Proefschrift, Wageningen.

Dit proefschrift.

2

Locale plaatsing van kunstmest kan de mate van onkruidgroei aanzienlijk verminderen.

Dit proefschrift.

3

In de tropen zal de onkruidkunde zich meer dan voorheen moeten richten op de analyse van teelt en teeltsysteem om door aanpassing van de teeltwijze de concurrentiepositie van het gewas ten opzichte van de onkruiden te verbeteren.

4

Wetenschappelijk onderzoek betreffende de tropische onkruidkunde dient, behoudens misschien experimenten onder goed te controleren omstandigheden, in de tropen te worden uitgevoerd.

5

De aard en de uitvoering van de Nederlandse ontwikkelingshulp aan Suriname na 1975 waren niet in overeenstemming met de doelstellingen van deze hulp, namelijk het vergroten van de economische zelfstandigheid van Suriname.

Bayah Mhango, 1984. Aid and dependence. The case of Suriname. Foundation in the arts and sciences, Paramaribo.

6

Uit een oogpunt van zelfbescherming van ontwikkelingslanden is het gewenst aan instellingen voor wetenschappelijk onderwijs in die landen een studierichting westerse politicologie en economie op te richten.

7

De algemene ambivalentie van de ontwikkelingssamenwerking komt ook op individueel niveau tot uiting. Met name de op arbeidscontract uitgezonden ontwikkelingsdeskundige zal, bewust of onbewust, niet geneigd zijn 'zichzelf overbodig te maken'.

8

De Nederlandse dierentuinen besteden in hun collectie te weinig aandacht aan de inheemse fauna, vooral met het oog op natuurbeschermingseducatie in eigen land.

9

Uitkap van hout en bosbouwkundige manipulaties ontwrichten een regenbos zozeer, dat het zijn andere dan houtleverende functies verliest, dit in tegenstelling tot wat de Graaf (1986) stelde, namelijk dat bij beperkte manipulaties en zuiveringen tropisch regenbos in Suriname nog steeds tropisch regenbos blijft.

Stelling 3 van N.R. de Graaf, 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Proefschrift, Wageningen.

M. Jacobs, 1981. Het tropisch regenwoud. Een eerste kennismaking. Coutinho, Muiderberg.

10

Het huidige 'jaarrond' aanbod van vroeger seizoensgebonden tuinbouwproducten leidt tot vervaging van seizoenbesef bij de consument.

11

Onkruidkunde zonder kruid is onkunde.

Stellingen behorende bij het proefschrift van A.P. Everaarts, 'Competition between crops and weeds in the Zanderij area of Suriname', Wageningen, 22 februari 1991.

Aan Meike, Marthe en Anna

Abstract

Everaarts, A.P., 1991. Competition between crops and weeds in the Zanderij area of Suriname. Doctoral thesis, Agricultural University, Wageningen. VII + 129 pp.

A weed flora rapidly built up with the cultivation of annual crops on two experimental farms in the Zanderij area of Suriname, despite the fact that the farms were newly established in forested areas. Studies indicated that without adequate weed control, significant yield losses occurred in groundnuts, sorghum and soybeans due to competition with weeds. Plant density of the crops was not affected, but competition with weeds reduced ground-cover and leaf area index. Competition affected growth rates, leading to lower yields. The nature of the competitive effects is discussed and data are presented on the spatial distribution of weed growth in the crops. To prevent yield reduction in groundnuts and soybeans, competition during the period of pod initiation should be avoided. In sorghum, competition must be prevented during the period of floret establishment. In groundnuts, a period of 15 weed-free days after planting prevented yield loss and the presence of too much weed at harvest. Yield losses in sorghum were prevented with about 20 weed-free days after planting. A period up to around 30 days was needed to attain negligible weed growth at harvest. It was necessary to weed soybeans up to around 30 days after planting to avoid yield loss and too much weed growth at maturity. The response of weeds to fertilizer application varied, depending on the weed vegetation and the nutrient applied. Both stimulation of growth and increase in weed density were observed. Band-placement of fertilizers in planter press wheel furrows considerably reduced weed growth when compared with broadcast fertilizers.

The investigation was carried out at the
Centre for Agricultural Research in Suriname (CELOS),
Anton de Kom University of Suriname,
Paramaribo, Suriname, and at the
Dept. Vegetation Science, Plant Ecology and Weed Science, and
Dept. Tropical Crops Science,
Agricultural University, Wageningen, The Netherlands

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Voorwoord

Het in dit proefschrift beschreven onderzoek werd gedurende de jaren 1981 tot 1984 uitgevoerd op het Centrum voor Landbouwkundig Onderzoek in Suriname, CELOS, te Paramaribo, in het kader van een samenwerkingsproject tussen de Anton de Kom Universiteit van Suriname en de Landbouwhogeschool, thans Landbouwuniversiteit, te Wageningen. Het veldwerk voor dit onderzoek werd verricht op de proeftuin Coebiti, gelegen in het Zanderij gebied van Suriname.

Velen ben ik erkentelijk voor hun bijdrage aan dit onderzoek. De collega's en medewerkers op het CELOS voor de plezierige en leerzame samenwerking gedurende de jaren in Suriname. De hier behandelde veldproeven hadden zonder de vakkundigheid van de heren Idoe en Harrybadjan, en de grote inzet van hun medewerkers en de assistenten Rinaldo Feliksdal en Marjan van Deurzen niet zoveel resultaat kunnen opleveren.

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De discussies met en de steun van projectleider J.F. Wienk waren van bijzonder belang. G. Liefstingh begeleidde met veel aandacht het onderzoek vanuit Nederland.

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D. Goense verrichtte het rekenwerk met betrekking tot de potentiële evapotranspiratie van de gewassen.

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Chapter I

GENERAL INTRODUCTION

Framework of the research

In 1977, a multidisciplinary research programme, aimed at investigating the possibilities for a year-round cultivation of annual crops on the loamy soils of the Zanderij area in Suriname, was started as a joint undertaking between the Anton de Kom University of Suriname (UvS) in Paramaribo and the Agricultural University, Wageningen (AUW), the Netherlands. The headquarters for this programme, known as "The permanent cultivation of rainfed annual crops on the loamy soils of the Zanderij formation", (Project LH/UvS 02), were at the Centre for Agricultural Research in Suriname (CELOS) in Paramaribo. The studies were made on two experimental farms, Coebiti and Kabo, located in the Zanderij area. Because little was known about the factors influencing the occurrence of weeds and their effect on crop growth on these experimental farms, a study of weed ecology and crop-weed competition was added to the programme in 1981. The joint research programme was terminated in 1983. Weed research was continued until the second half of 1984. Part of the results are presented in this paper.

Brief physiography of Suriname

Suriname is situated on the north-east coast of South America, between 2° and 6° North and 54° and 58° West. The country has a total area of about 163 000 km^2.

Three major physiographic regions can be distinguished (Fig. 1):

(a) the coastal plain;

(b) the Zanderij or 'Dek' landscape;

(c) the interior uplands.

The total area of the coastal plain is about 20 000 km^2. Its soils consist mainly of heavy-textured marine clay deposits. The topography is almost flat, with the highest elevation about ten metres above sea level.

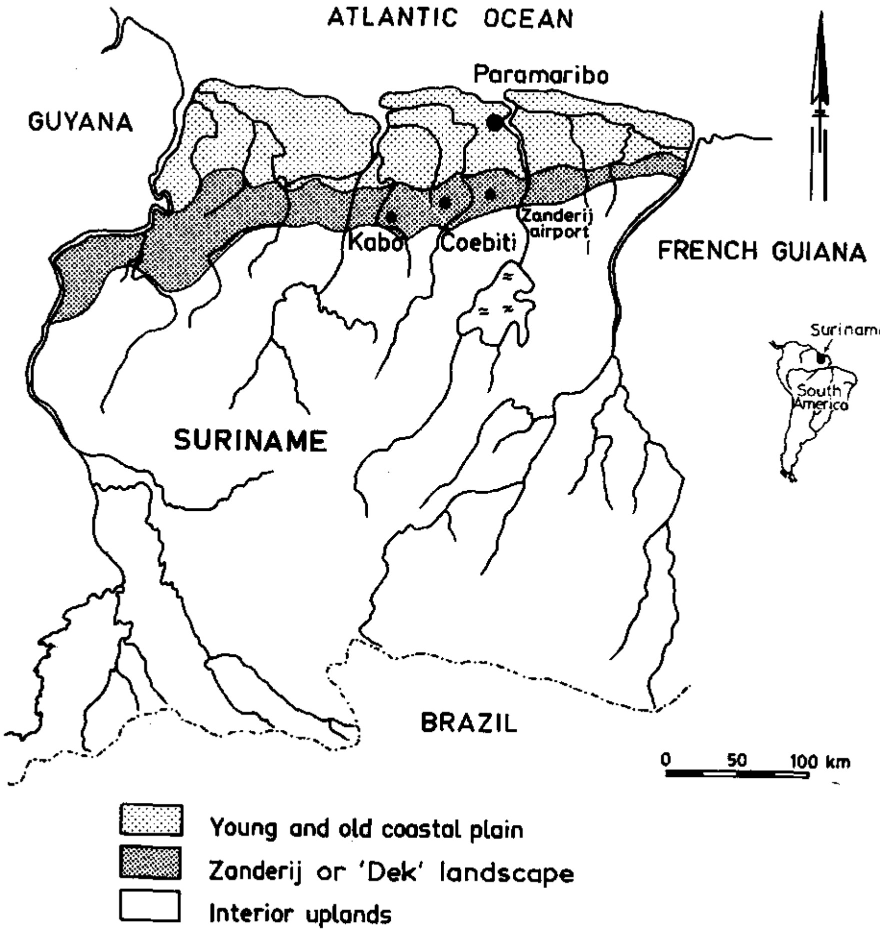

Fig. 1. The major physiographic regions of Suriname.

Two regions can be distinguished. The old coastal plain of Pleistocene and early Holocene origin and the young coastal plain, consisting of more recent deposits. In the young coastal plain, especially in the central and eastern parts, complexes of shell containing sand ridges are found.

Adjacent to the coastal plain lies the Zanderij or 'Dek' landscape, here referred to as Zanderij area (in literature also indicated as Zanderij formation). This area is a more or less continuous east-west running belt, five to ten kilometres wide in the east and sixty to seventy kilometres wide in the west, covering about 9 000 km^2. Its soils are derived from fluviatile Pliocene sediments and are predominantly sandy. The topography is flat to slightly undulating, with the highest elevation about fifty metres above sea level.

The interior uplands cover more than four fifths of the country. Their predominantly residual soils have mainly formed from Pre-cambrian rocks. The landscape is mainly gently to moderately rolling, with locally some mountainous areas. The highest mountain reaches 1 280 metres above sea level (for details see: van der Eyk, 1957; Brinkman and Pons, 1968; Krook and Mulders, 1971; Bosma et al., 1984; Poels, 1987).

Agriculture

Agriculture in Suriname is mainly limited to the young coastal plain and to an area of the old coastal plain south of the capital Paramaribo. Rice, citrus, sugar cane and bananas are important crops. Vegetables and other food crops are usually only grown on a small scale, mainly on the sand ridges. Agriculture in the very thinly populated Zanderij area and interior uplands was, until recently, limited to shifting cultivation. In recent years on the interior uplands, oilpalm cultivation has been introduced, and pastures have been developed. Pastures have also been developed, on a limited scale, in the Zanderij area.

In the coastal plain, the combination of heavy soils and high precipitation limits the mechanization of dry-land crop cultivation. The low permeability of the heavy soils necessitates the construction of cambered beds for the run-off of excess water, and because most of the land lies below the high-water mark, extensive drainage systems, in the form of polders, are required.

The soils of the Zanderij area chemically are less fertile, but they have better physical properties and they are well drained. These conditions offer better opportunities for mechanized farming. When, in the 'sixties, the Zanderij area was opened for timber exploitation, agricultural interest in the area developed (Krook and Mulders, 1971; van Amson, 1975; Schroo, 1976).

The Zanderij area

General

The Zanderij area is largely uninhabited and is covered by natural vegetation. Agricultural activities of the sparse population are limited to shifting cultivation. In one location, however, pastures have been established on a limited scale. Data on forestry and forestry research have been published by de Graaf (1986), Jonkers (1987) and Poels (1987).

Climate

According to Köppen's classification, most of Suriname has a tropical rain forest climate (Af) or a tropical monsoon climate (Am).

Mean annual rainfall is about 2 220 mm. Distribution is bimodal and four seasons are distinguished. A long rainy season from April to August, a long dry season from August to November, a short rainy season from November to January and a short dry season from January to April. The distinction between the seasons, however, is not clear-cut and seasons may set in irregularly.

Mean annual temperature is 27 °C.

Most of the Zanderij area has a tropical rain forest climate. The most western part has a tropical monsoon climate. The area where the experimental farms Coebiti and Kabo are located has a tropical rain forest climate. Data concerning some climatological parameters of the Zanderij area are given in Table 1. These data are based on observations at the climatological station located at Zanderij airport (Fig. 1).

The average monthly maximum or minimum temperature does not fluctuate much throughout the year. The highest temperatures are around October and the lowest in January and February.

Table 1. Climatological data Zanderij station, 1958 - 1982 (Goense, 1987).

Month	J	F	M	A	M	J	J	A	S	O	N	D
Maximum temperature, °C	30.6	30.8	31.3	31.6	31.3	31.5	32.0	33.1	34.0	34.0	33.1	31.4
Minimum temperature, °C	21.7	21.3	21.7	22.3	22.7	22.5	22.2	22.3	22.4	22.4	22.6	22.1
Sunshine duration, n N^{-1}	0.49	0.51	0.48	0.48	0.46	0.51	0.63	0.73	0.77	0.76	0.68	0.53
Precipitation, mm m^{-1}	200	136	146	223	286	309	251	181	103	95	117	187
Evaporation^{+}, mm d^{-1}	3.9	4.1	4.1	4.2	4.0	4.1	4.5	5.3	5.6	5.6	4.9	3.8

($^{+}$Class-A open pan, 1973 - 1980).

Average monthly rainfall varies from 95 mm in October to 309 mm in June.

The mean monthly sunshine duration (as measured from 7 a.m.to 5 p.m.) reaches a maximum in September and then decreases and varies little from December to June, after which sunshine duration increases again. The amount of sunshine does not closely follow the rainfall pattern. Rainfall in the second half of the long rainy season is more concentrated in short, heavy showers, which goes with an increase in mean sunshine duration (Goense, 1987).

Free water evaporation varies from 3.8 mm d^{-1} in December to 5.6 mm d^{-1} in September and October.

During the year relative humidity at 8 a.m. varies from 93 per cent in January and February, to 86 per cent in September and October. Depending on the season relative humidity during the day (2 p.m.) varies from 51 per cent to 70 per cent (Goense, 1987). Details on climatological records available for the Kabo experimental farm are given by Poels (1987).

Soils

The soils of the Zanderij area can be grouped into bleached white sands, brown sands, and brown sandy loams (Boxman et al., 1985). The white and brown sands are not suitable for agriculture due to their extremely low chemical fertility and their very low water-holding capacity.

The brown sandy loams are better suited, but are still difficult to manage. They make up around 30 per cent of the total Zanderij area. The brown sandy loams belong to the yellow kaolinitic Oxisols intergrading towards Ultisols (Bennema, 1982). They are described as very deep, moderately well to well-drained soils, with a brown loamy sand to sandy loam topsoil and a dull brown to brownish yellow or orange sandy clay loam subsoil.

Some chemical and physical properties of brown sandy loams under forest are given in Table 2. The main chemical constraints for agricultural use of the brown sandy loams are acidity, and a deficiency in both primary and secondary nutrients. Physical constraints are a low water-holding capacity and a weak structural stability (Schroo, 1976; Soe Agnie, 1982; Boxman et al., 1985). This type of soil is generally referred to as a low fertility acid soil (Wienk and de Wit, 1982).

Table 2. Some chemical and physical properties of brown sandy loams under forest (Boxman et al., 1985).

Sample depth, cm	0-20	20-40	40-60
Org. C, g kg^{-1}	12	8	4
Org. N, g kg^{-1}	0.8	0.5	0.3
pH-KCl	3.7	3.9	4.1
pH-H_2O	4.2	4.5	4.7
Exch. Ca, mmol(+) kg^{-1}	1.5	0.5	0.3
Mg, mmol(+) kg^{-1}	0.9	0.3	0.3
K , mmol(+) kg^{-1}	0.4	0.3	0.1
Na, mmol(+) kg^{-1}	0.1	0.1	0.1
Al, mmol(+) kg^{-1}	10.2	9.9	7.3
ECEC, mmol(+) kg^{-1}	13.1	11.1	8.1
100 x exch. Al/ECEC	78	89	90
CEC, pH7, mmol(+) kg^{-1}	34	24	18
P-Bray I, mg kg^{-1} P	2	1	1
Porosity, volume fraction	0.50	0.46	0.46
Available moisture, volume fraction	0.11	0.10	0.09

(ECEC = Effective Cation Exchange Capacity; CEC = Cation Exchange Capacity).

Poels (1987) recently reviewed Zanderij soils and soil research relevant to the Kabo area (Fig. 1). Detailed descriptions of the soils of the experimental farms have been given by van Amson et al. (1974) and Bruin and Tjoe-Awie (1980) for Coebiti and Kabo respectively.

Natural vegetation

Most of the Zanderij area is covered by evergreen seasonal forest. On the bleached white sands, the vegetation is mainly a low savanna vegetation of grasses and shrubs or a savanna forest (Schulz, 1960; Heyligers, 1963; van Donselaar, 1965; Teunissen, 1978).

The experimental farms Coebiti and Kabo

Coebiti and Kabo are isolated experimental farms surrounded by forest. They are located in the Zanderij area in the district Saramacca.

Coebiti (5°20′ N, 55°30′ W, Fig. 1) was established in 1969 by the Foundation for Experimental Farms in Suriname (STIPRIS) on soils representative of the Zanderij area. Originally comprising 73 ha, the farm was extended to 100 ha in 1975. At first, research at Coebiti was focussed on perennial crops and pastures. Initially, unused areas were planted with tropical kudzu (*Pueraria phaseoloides* (Roxb.) Benth.). From 1972 onwards, research on annual food crops was also done. Research at Coebiti was carried out by the Agricultural Experiment Station (Landbouwproefstation), Paramaribo, and the Centre for Agricultural Research in Suriname (CELOS), also at Paramaribo. The research done by CELOS was only concerned with annual crops, and from 1977 onwards this work was continued within the framework of the joint research programme of the UvS and AUW (see under Framework of the research).

The 30 ha experimental farm Kabo (5°16′ N, 55°43′ W) was established in 1978/79 within the plan of the joint research programme of the UvS and AUW, to study the possibilities for year-round cultivation of rainfed annual crops, starting with clearing of the forest. Kabo is situated some forty kilometres south-west of Coebiti (Fig. 1).

In 1987, a detailed study was completed on the possibilities for mechanized farming of annual crops in the Zanderij area of Suriname, with special reference to soil tillage, workability and timeliness of farm operations (Goense, 1987). This study was carried out at the Coebiti and Kabo experimental farms. Prospects for mechanized farming were evaluated with a linear programming model and it was concluded, that under favourable socio-economic conditions and skilfull management, the model maize and groundnuts farm defined, would be a practical proposition.

Very recently a detailed report on the investigations carried out in the joint research programme of the UvS and AUW (Project LH/UvS 02, see under Framework of the research) became available (Janssen and Wienk, 1990). In this report a full account of the project and its research results is presented.

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Chapter II

WEEDS AND WEED CONTROL AT COEBITI AND KABO

Introduction

Research on the occurrence and control of weeds in Suriname has been focussed on a variety of subjects. Wouters (1965) listed weeds of wet rice, with notes on their control, while Dirven made observations on the weed flora in field crops on loamy sands of the old coastal plain (1968) and on the weed flora of fallow rice fields (1970). Effects of soil tillage on weed growth were mentioned by Kouwenhoven (1973) and van der Sar (1976). Dumas and Ausan presented weed control research data for maize (1978b) and discussed weed control experiences and research in groundnut (1978c). Studies were made on the role of weeds in the incidence of 'hartrot' or 'fatal wilt' of palms (Kastelein, Karyosemito and Segeren, 1984; Segeren and Alexander, 1984; Segeren, Sparnaay and Kastelein, 1984; Kastelein, 1987). Keisers (1984, 1985) studied the effect of red rice on yield of wetland rice and possible cultural control of red rice. Keisers and Paidin (1986) evaluated post-emergence herbicide treatments for weed control in wetland rice.

Available data on weeds at the experimental farms Coebiti and Kabo are discussed below, with emphasis on the introduction of weeds and on weed control in annual crops.

Weed flora

Coebiti, the first weeds

Perhaps the first reference to weeds in fields at Coebiti after the clearing of the forest is Hoving (1973), who reported that in his 1972 experiments, i.e. three years after clearing, very little weed growth developed, except for some spots in groundnut and mungbean plots on the more heavy soils, where quite a few grasses appeared. The weeds, however, were not identified. In a report on observations on leguminous crops at Coebiti between December 1972 and May 1973, van Slobbe and Wienk (1973) mentioned *Physalis* sp. and *Hyptis* sp. as the predominant dicotyledonous weeds in these observations. Grasses were not or hardly found. Weed growth in general, however, was very limited due to drought. Van Muijlwijk (1974a) noted that in a 1973 groundnut experiment, weeds, especially grasses (*Digitaria* spp.), were causing problems. Broadleaved weeds were present (a.o. *Physalis* sp.), but not to a serious degree. In another experiment during the same year (van Muijlwijk, 1974b), weed incidence was found to be low and weed growth consisted almost completely of dicotyledons, especially *Borreria latifolia* (Aubl.) Schum., while *Physalis angulata* L. and *Croton trinitatis* Millsp. (cited as C. miquelianus L.) were also found. Cyperaceae were dominant in wet places.

Budelman and Ketelaars (1974) identified weeds at Coebiti in late 1973 or early 1974 and listed the following species: *Andropogon bicornis* L., *Borreria latifolia*, *Digitaria* cf. *horizontalis* Willd., *Euphorbia thymifolia* L., *Lindernia crustacea* (L.) F.v.M., *Ludwigia erecta* (L.) Hara (cited as Jussieua erecta L.), *Mariscus ligularis* Urb., *Physalis angulata* and *Vernonia cinerea* (L.) Less.. Van Muijlwijk (1974c) mentioned as weeds at Coebiti, *Alternanthera sessilis* (L.) R.Br., *Borreria latifolia*, *Digitaria horizontalis*, *Ludwigia erecta* (cited as Jussieua erecta), *Mariscus ligularis*, *Physalis angulata*, *Portulaca oleracea* L. and *Torulinium ferax* Urb.. *Digitaria horizontalis* and *Portulaca oleracea* were found as weeds in a 1974 cowpea variety trial (van Muijlwijk, 1974d).

In 1975 Bink reported on weeds in a 1974 experiment, of which the following had not been mentioned previously: *Amaranthus dubius* Mart., *Cyperus* sp., *Eleusine indica* (L.) Gaertn., *Emilia sonchifolia* (L.) DC., *Euphorbia hirta* L., *E. hypericifolia* L.[1] , *Oldenlandia corymbosa* L., and *Paspalum conjugatum* Berg.. These data concern weeds in annual crops. No data were found for weeds in the early observations on perennial crops and pastures.

The annual crops were planted in initially unused areas that had been planted

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[1]*Euphorbia hypericifolia* was not found again at Coebiti, and this record probably represents *Euphorbia hyssopifolia* L., a closely resembling species commonly found at Coebiti (Everaarts, unpublished data).

with tropical kudzu (*Pueraria phaseoloides* (Roxb.) Benth.) after clearing. Although the kudzu cover is likely to have hampered the establishment and spread of weeds, once the cultivation of annual crops had started on these locations, the occurrence of weeds seems to have increased rapidly.

The above data illustrate that at the end of the first two years of annual crop cultivation, a substantial number of weed species found in crops in other areas in Suriname (Dirven, 1968; Dumas and Ausan, 1978a; Segeren, Sparnaay and Kastelein, 1984) were present at the Coebiti farm. More species may have been present but gone unnoticed or unmentioned.

From 1975 onwards more reports appeared mentioning weed species in experiments at Coebiti (Muileboom-Muffels, 1975; van de Weg, 1975; van de Wall, 1975; Bink, 1976; van der Sar and Vermaat, 1978). Later on, inventory studies of weeds were made at Coebiti (van Grootveld, 1979; Kloos, 1980; Segeren, Sparnaay and Kastelein, 1984).

Kabo, the first weeds

The forest vegetation was surveyed prior to clearing. Only a few herbaceous plants were present and no species known as weeds were found. To check the presence of weed seeds in the soil, several samples consisting of litter and topsoil were taken and spread out for germination and identification of seedlings. Only one genus, *Cecropia* (Moraceae), a well known tree species of secondary forest, could be identified with certainty, and no conclusions could be drawn (Anon., 1980).

In 1979, the year in which the clearing of Kabo was completed, van Grootveld (1979) found that prior to land preparation for crop cultivation, the grasses *Digitaria horizontalis*, *Echinochloa colonum* (L.) Link and *Eleusine indica*, and the sedge *Fimbristylis littoralis* Gaud. (cited as F. miliacea (L.) Vahl) occurred spotwise all over the cleared area. Furthermore, he reported that under the same conditions, the broadleaved weeds *Amaranthus dubius*, *Borreria laevis* (Lam.) Griseb., *Conyza canadensis* L., *Isotoma longiflora* (L.) Presl (cited as Laurentia longiflora L.), *Ludwigia erecta* (cited as Jussieua erecta) and *Oldenlandia corymbosa* were found as species occurring as single plants, often the only plant at Kabo[2]. A few months after this first observation, the situation had not changed much, except for an increased number of sedge species, now also including *Cyperus rotundus* L. (van Grootveld, 1979). A quick establishment of weeds and herbaceous wasteland plants appears to have taken place at Kabo, because in 1980, two years after clearing had started, Kloos (1980) reported about 46 such species.

These results show that somehow, once the site had been cleared from forest and agricultural activities had started, many weed and wasteland species appeared and established themselves in this isolated location in the interior.

Weed invasion

No data on the vegetation of the Coebiti farm prior to clearing and cultivation have been found. Typical agricultural weeds, however, do not occur in undisturbed tropical rain forests. Nevertheless, it cannot be excluded that weed species later on occurring at Coebiti may have been present in the farm area before clearing, as Coebiti was cleared from exploited forest. The construction of a road system in the Zanderij area in the 'sixties, the clearing of the forest, the establishment of a forestry nursery, and the planting of *Pinus caribaea* Morelet near the future Coebiti farm area, together with the exploitation of the farm area itself, may have facilitated the introduction of plants formerly foreign to the area. In the Brokopondo district of Suriname, alien vegetations developed following road construction (Ketelaars and Budelman, 1976). Yet even exploited forest, such as at Coebiti, is an unlikely habitat for agricultural weeds and Kabo was cleared from undisturbed forest. But at both locations a weed flora flourished with the beginning of agricultural activities.

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[2]Of these six species *Conyza canadensis* and *Isotoma longiflora* have never been found again at Kabo, and these names are suspected to represent misidentified specimens of *Conyza bonariensis* (L.) Cronq. and *Erechtites hieracifolia* (L.) Rafin. ex DC. respectively, while archive material at CELOS makes it likely that *Borreria laevis* actually was *Borreria latifolia*.

In Table 1, some selected weeds of crops grown in the coastal plain of Suriname, and which are also found at Coebiti and Kabo, are presented. None of these species have their natural habitat in the forest. Some may have come to Coebiti or Kabo from ruderal sites or from shifting cultivation plots in the Zanderij area. However, given the very frequent agriculturally

Table 1. Plants found as weeds of crops in the coastal plain of Suriname, also found at the experimental farms Coebiti and Kabo in the Zanderij area (Dirven, 1968; Dumas and Ausan, 1978a; Kloos, 1980; Everaarts, unpublished data).

AMARANTHACEAE	GRAMINEAE
Alternanthera sessilis (L.) R.Br.	*Cenchrus echinatus* L.
Amaranthus dubius Mart.	*Cynodon dactylon* (L.) Pers.
	Digitaria horizontalis Willd.
COMPOSITAE	*Eleusine indica* (L.) Gaertn.
Eclipta prostrata (L.) L.	*Echinochloa colonum* (L.) Link
(Eclipta alba (L.) Hassk.)	
Emilia sonchifolia (L.) DC.	ONAGRACEAE
Vernonia cinerea (L.) Less.	*Ludwigia hyssopifolia* (G. Don) Exell
	(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'Hérit.	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.	

related contacts with the coastal plain, it is most likely that the majority of the species were brought from outside the Zanderij area, i.e. from the coastal plain.

No research has been done to investigate precisely how the species could possibly have got to Coebiti and Kabo. The most likely explanation would be that seeds or plant fragments had stuck to equipment, footwear or clothing. Seeds or plant parts may also have been brought in with jute bags or as impurities of crop seeds and other planting material. Agricultural machinery of the Centre for Agricultural Research in Suriname (CELOS) at Paramaribo, was frequently moved back and forth to Coebiti, and weed species could easily have been transported in this way. For research purposes, mulching material harvested from the CELOS experimental fields was carried to Coebiti, and seeds or fragments of weeds could have been brought along. Later on, regular traffic and exchange of equipment between Coebiti and Kabo is likely to have contributed to the rapid build up of the weed and wasteland flora at Kabo.

Because of the isolation of the experimental farms, the distance to the nearest agricultural area of any significance (>45 km north as the crow flies), and the natural vegetation of the roadsides involved, it is unlikely that other means of dispersal, such as wind, birds or 'travelling' along the roadsides have contributed much to the build up of the weed flora of Coebiti and Kabo.

Practical implications

General sanitary measures such as the use of clean planting material, and the prevention of the dispersal of weed seeds or fragments through their adherence to people or objects, contribute to prevent a rapid build up of a noxious weed flora in newly-opened agricultural areas such as Coebiti and Kabo. To prevent further spread, especially of weeds that are difficult to control, e.g. *Cyperus rotundus*, it is essential to clean and check equipment before moving from field to field.

Weed control

Research

Probably the first experiment at Coebiti, in which specific attention was paid to weed control, was done by Bink (1975) in 1974. He studied the effects of leaf spot (*Cercospora* spp.) control, fertilizer application and removing weeds from plant rows at 34 days after planting, on the yield of groundnuts. The whole experiment was weeded twice between the rows, at 10 and 34 days after planting, while paraquat had been applied pre-planting, one week after tillage. *Cercospora* control and fertilizer application significantly increased yields, but weeding in the rows had no effect. However, at harvest the dry weight of weeds in fields with *Cercospora* control, was about one third of that in fields without *Cercospora* control. An effect mainly attributable to a more well-developed crop canopy. The application of fertilizer did not affect weed growth. Removal of weeds from plant rows 34 days after planting reduced the amount of weeds at harvest time by fifty per cent. *Cercospora* control, fertilizer application and weeding together reduced weed growth to one sixth of that of the plots without any treatment. Although no effect of weed growth in the rows on yield was found, the results of this trial indicate the importance of a healthy crop in relation to competition with weeds.

In 1975, the application of three different herbicides, with or without hilling, in groundnuts was studied for effects on yield and weed growth (Muileboom-Muffels, 1975). The herbicides prometryne (1.25 kg ha^{-1} a.i.), diphenamid (5.60 kg ha^{-1} a.i.), and paraquat (0.5 per cent Gramoxone solution), were applied pre-emergence, while hilling was done at four weeks after planting. In the plots treated with paraquat, one additional hand-weeding between the rows was done at three weeks. No significant differences in yield were found between the herbicide treatments. A slightly beneficial effect of hilling on yield was observed only where prometryne had been applied. Hilling significantly reduced weed growth between but not in the rows.

In a trial comparing three methods of tillage, ploughing, rotovating and minimum tillage, it was noticed that weed growth was generally poorest on the ploughed plots and strongest on the minimum tillage plots, with rotovating generally in between (van der Sar, 1976). Under dry conditions sufficient control of weeds could be achieved either by mechanical- or by hand-weeding. Under wet conditions, paraquat was sprayed under a protective shield.

Weeding in maize, sorghum, soybeans and groundnuts, significantly increased yields in two experiments (van der Sar and Vermaat, 1978). In the early maturing crop mungbean, weeding had no clear effect on yields. Cowpea, another short duration crop, benefited most if weeding was done only once, a second weeding resulted in lower yields due to damage to the crop. Because of a more closed canopy, the leguminous crops generally competed stronger with the weeds than maize and sorghum.

In some field trials at Coebiti with the crop cultivation methods of the time, mechanical weed control methods, sometimes combined with the use of paraquat, became more and more inadequate in controlling the weeds (especially *Eleusine indica*). Therefore the use of herbicides, other than paraquat, was investigated to improve weed control. Details and results of these investigations were reported in the quarterly reports of the Centre for Agricultural Research in Suriname (CELOS) and in the annual reports of the research programme: "The permanent cultivation of rainfed annual crops on the loamy soils of the Zanderij formation", at CELOS, Paramaribo (see Chapter I).

In a non-replicated study, atrazine at 2.8 kg ha^{-1} a.i. proved to be 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, this herbicide adversely affected crop emergence irrespective of how it was applied, and depressed the crop yield when applied before planting without soil incorporation. Leguminous crops planted on the observation site after harvest, showed no signs of damage due to atrazine residues. Alachlor at 2.16 kg ha^{-1} a.i., also applied pre-planting, with or without soil incorporation, and pre-emergence (post-planting, cassava), did not produce visible signs of damage to groundnuts, soybeans, cassava, or mungbean. When applied pre-emergence it retarded growth of cowpea, but this did not result in yield loss. Weed growth was reduced by all herbicide treatments. However, weed growth was moderate. Mungbean and groundnut yields were higher with herbicide application, but maize and cowpea yields were largely unaffected. Cassava and soybean yields were not determined.

The damage to sorghum when atrazine was applied at 2.8 kg ha^{-1} a.i., led to an experiment in which pre-emergence application of atrazine at lower concentrations, viz. 0.4, 0.8, 1.2 and 1.6 kg ha^{-1} a.i. were compared with no weeding and with weekly hand-weeding up to nine weeks after planting. Hand-weeding resulted in the highest yield. Damage by atrazine was not noted either on emergence or on development of the crop, but it was concluded that weed growth was insufficiently controlled at any concentration. From another study, in which pre-emergence applications of atrazine, with or without supplementary hand-weeding, and post-emergence applications were compared, it was concluded that atrazine in sorghum could probably be best applied as a post-emergence herbicide about one week after planting. No conclusions could be drawn about the optimum rate.

In a trial with maize, comparing direct planting (no tillage) and planting in 0.10 m wide, 0.06 m deep rotovated strips (minimum tillage), the tillage system had no effect on weed density six weeks after planting, but weed weight at harvest was higher with direct planting. The method of planting 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 an experiment with sorghum, in which the post-emergence application of atrazine (2.5 kg ha^{-1} a.i. at 16 days after planting) and the pre-emergence application of prometryne (1.25 kg ha^{-1} a.i.), cyanazine + propachlor (1.5 + 4 kg ha^{-1} a.i.) and terbutryne (2.4 kg ha^{-1} a.i.) were compared with hand-weeding once at 23 days after planting, the highest yields were obtained with the application of terbutryne and the combination of cyanazine + propachlor. Control of weeds, as judged visually at six weeks after planting, was generally satisfactory with all treatments. Control of *Cenchrus echinatus* L., however, posed problems (Ausan and Pultoo, 1984).

All the above-mentioned observations were made at Coebiti. The data only concern weed control in annual crops. No literature was found on weed control experiments in other crops. No observations on weed control were made at Kabo.

These results show that knowledge concerning weed control methods under the local conditions is still fragmentary. Competition between weeds and crops, resulting in loss of yield certainly occurs, however, and weed control has proved to be essential.

Weed control practices

Weed control practices in annual crops (including cassava) in the early experiments at Coebiti were hand-weeding with either a hoe or a Dutch hoe, while herbicides (mainly paraquat) have also been applied. Mechanical hoeing and rotovating were also tried, as well as hilling in groundnut. When soil conditions limited tillage, paraquat was used as a post-emergence spray under a protective shield between rows. Gradually, the emphasis was placed exclusively on chemical weed control.

In observations made by the Agricultural Experiment Station (Lata, 1983), the herbicides atrazine and alachlor were applied for control of weeds.

During the last years of the research programme on annual crops (see Chapter I) weed control methods generally consisted of post-planting spraying of alachlor at 2.4 kg ha^{-1} a.i. in cassava and the pre-emergence application of alachlor at the same rate in groundnuts, soybeans, cowpea, mungbean and maize. When maize was cultivated after groundnuts, the application of alachlor was followed by an application of atrazine at 2.5 kg ha^{-1} a.i., ten to fourteen days after emergence, primarily to control volunteer groundnut. Weeds in sorghum were controlled by applying atrazine at 2.5 kg ha^{-1} a.i., ten to fourteen days after emergence. Paraquat as a pre-emergence application, at 0.4 kg ha^{-1} a.i., was used in combination with the herbicides mentioned in no tillage or minimum tillage cultivation. A spray-volume of 400 l water per hectare was recommended.

Some euphorbiaceous weeds were not sufficiently controlled by alachlor at the applied rate. Overall weed control with these herbicide regimes was, however, generally satisfactory. Nevertheless, under conditions such as excessive rainfall just after application, there was the possibility that the effectiveness of the herbicides was reduced, sometimes necessitating supplementary weeding by hand. Mowing and disc-harrowing of the fallow vegetation remained essential to reduce the regrowth of weed fragments, especially where grasses or creeping-rooting weeds dominated the fallow vegetation.

Well-known noxious weeds, such as *Cyperus rotundus*, continued to pose problems.

Although some studies were made, the rates and types of herbicides that were used for weed control in annual crops were not based entirely on locally developed recommendations, and the same control could possibly be achieved by using lower dosages of the same or other herbicides, whether or not in combination with a different timing of application.

Weed control in other crops

Information on the need for weed control or on weed control methods in crops at Coebiti other than the ones discussed above is limited.

Weeds in plantain were initially controlled with herbicides (no details given), but later by hand-weeding (machete) (Parsan, van der Weert and Lenselink, 1974). Soe Agnie (1978) presenting the results of experiments with fertilizer application in sugar cane, mentioned only that weed control and crop protection were carried out, if necessary. Soerodimedjo (1982) discussed pineapple experiments, but did not give data on weed control. Earlier it had been mentioned that a herbicide, hand-weeding and covering the soil with black plastic had been applied for control of weeds (Soerodimedjo and de Freitas, 1979). In observations on citrus, weeding around the trunk was done by spraying paraquat, while the rest of the field was covered by tropical kudzu. After die-off of the ground-cover, due to drought, weeding was done by mowing with a tractor-mounted rotary mower (Mansour and Spong, 1985).

In a first observation in a grass/crop rotation study, *Brachiaria* sp. demonstrated a longer regrowth period after a maize crop than *Digitaria swazilandensis* Stent, which makes weed control necessary (Tjong A Hung, 1978). No mention of weeds was made by Brandon-van Steyn and Simons (1983), or by Simons (1984) in experiments with grasses. Experimental plots in their observations were not large, however, and weed growth probably was no problem.

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Chapter III

EFFECTS OF COMPETITION WITH WEEDS ON GROWTH AND YIELD OF GROUNDNUTS

Introduction

In many tropical countries, weed competition may cause serious yield losses in groundnuts (*Arachis hypogaea* L.) (Bunting and Lea, 1957; Goldson, 1967; Ishag, 1971; Raj and Wong, 1975; Carson, 1976; Rethinam et al., 1976; Drennan and Jennings, 1977; Krishnamurthy et al., 1981; Lagoke, Choudhary and Tanko, 1981; Raghvani, Goyal and Patel, 1984; Yadav, Singh and Bahn, 1984; Singh et al., 1985; Hamada, Babiker and Khalifa, 1988).

Competition between crop and weeds may vary, among other factors, with local conditions (Smartt, 1964; Schiller, Prasart Dogkeaw and Prasit Jina, 1976), cultivars (Brown, 1965), fertilizer application (Ashrif, 1967), season (Hamdoun, 1977) and type of weed flora (Hamada, 1988).

The published results suggest that, in general, weeding during the first four to about eight weeks after planting is essential.

A brief review of weed control in tropical groundnuts is given by Moody (1979). Moody, Robles and Floresca (1986) presented a review of weed control in groundnuts in the Philippines.

Research results and practical experience regarding weed control in groundnuts in Suriname have been discussed by Dumas and Ausan (1978). In the only study on competition (Oomkes, unpublished), a six week period after planting without weed control caused no yield reduction, but an eight week period reduced the yield. Without any weed control yield reduction was 54 per cent. The study was done in the coastal plain of Suriname.

This chapter reports the results of two experiments in which the effects of weeds on growth and yield of groundnuts in the inland Zanderij area of Suriname were studied.

Materials and methods

General

The experiments were carried out at the experimental farm Coebiti (see Chapter I), during the late long rainy season of 1982 (Expt 1) and the short rainy season of 1982-83 (Expt 2). Data on rainfall during the experiments are presented in Fig. 1.

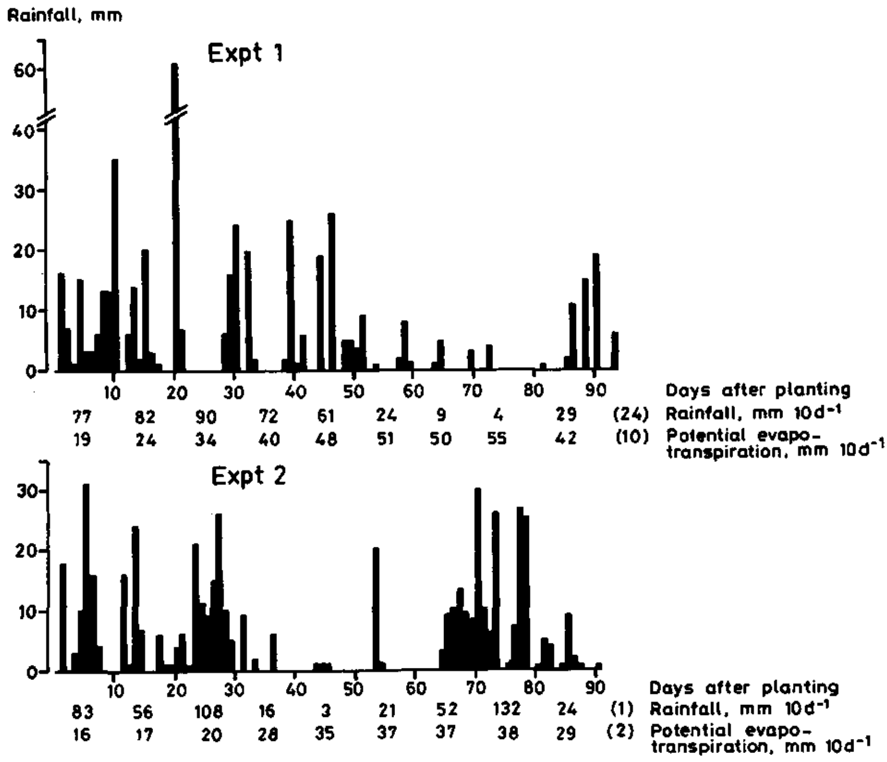

Fig. 1. Daily rainfall, and rainfall and potential evapotranspiration per ten days during the experiments.

To evaluate competition for water between crop and weeds, potential evapotranspiration of the crop during the experiments was calculated as free water evaporation x crop coefficient (Fig. 1). Free water evaporation was calculated according to the Penman equation, as amended by Doorenbos and Pruitt (1977). The crop coefficient was taken as 0.45 during the first 10

DAP[1], subsequently increasing linearly to 0.95 at mid-season (45 DAP) and then decreasing linearly from 80 DAP onwards to 0.55 at harvest.

The soils of the experimental fields are a predominantly sandy (Expt 1) and a sandy loam soil (Expt 2) and are acid and of low fertility. They are classified as yellow kaolinitic Oxisols intergrading towards Ultisols. Soil chemical properties are given in Table 1.

Table 1. Chemical properties of the soil (0-20 cm) of the experimental fields.

	Expt 1	Expt 2
Org. C, g kg^{-1}	8.3	16.2
Org. N, g kg^{-1}	0.6	1.3
pH-KCl	4.5	4.2
pH-H_2O	-	5.3
Exch. Ca, mmol(+) kg^{-1}	10.0	12.8
Mg, mmol(+) kg^{-1}	0.4	4.9
K , mmol(+) kg^{-1}	0.3	2.0
Na, mmol(+) kg^{-1}	0.2	1.4
Al, mmol(+) kg^{-1}	1.9	4.7
ECEC, mmol(+) kg^{-1}	12.7	25.9
100 x exch. Al/ECEC	15	18
CEC, pH7, mmol(+) kg^{-1}	23.8	43.9
P-Bray I, mg kg^{-1} P	30.7	29.6

(ECEC = Effective Cation Exchange Capacity;
CEC = Cation Exchange Capacity).

Cultivation practices

Before soil preparation, the experimental fields were limed at the rate of 400 kg ha^{-1} Ca. Seeds were machine-planted in rows 0.5 m apart, at 0.105 m in the row, immediately after disc-harrowing, ploughing and harrowing. Open spaces were replanted at emergence, resulting in densities of 160 000 (Expt 1, 20 DAP) and 175 000 (Expt 2, 14 DAP) plants ha^{-1}. At planting, *Rhizobium* inoculum was given and 18 kg N, 37 kg P and 74 kg K per hectare were band-placed near the seeds. Around four weeks after planting, gypsum, at the

[1] DAP: Days After Planting

rate of 29 kg ha^{-1} Ca, was applied over the rows. The early maturing Spanish type cultivar Matjan was used in both experiments. A fungicide for leafspot and rust control was routinely applied. Seeds were desinfected with a fungicide in the second experiment, but not in the first. Harvesting was done manually at 94 (Expt 1) and 91 (Expt 2) DAP.

Experimental procedures

The experiments had a randomized complete block design, replicated five times.
There were two series of six treatments. One series consisted of:

(a) keeping the crop weed-free, by hand-weeding, for six periods of an increasing number of days from planting onwards, after which time weed growth was permitted.

The other series consisted of:

(b) allowing the weed vegetation to develop freely for identical periods as under (a), after which time the crop was weeded, and kept weed-free by hand.

The plots consisted of four 7.5 m long rows and were subdivided into two 3 m long subplots comprising both centre rows. One subplot was set aside for the determination of final pod yield and yield components.

In the other subplot at the end of each weed-free period or period without weed control, the following observations were made:

- The degree of ground-cover of crop and weed vegetation was visually estimated;
- Of five crop plants the above-ground parts and pods were pooled and analysed for N, P and K concentrations;
- Five other crop plants were used to determine main stem length (up to the node with the last fully unfolded leaf), the number of nodes on the main stem (the cotyledonary node as first node) and the number of branches, leaves and pods present. Total leaf area of these five plants was estimated using the punch disc method, punching, as a rule, twelve leaflets per plant. Dry weight of leaflets, stems (including leaf-stalks and gynophores)

and pods of these plants was determined after oven-drying at 85 °C (24 h) and 105 °C (2 h);
- The remaining plants in the subplot were counted and the dry weight of their above-ground parts and pods, was determined;
- In treatments (b), two 0.5 x 0.6 m samples of the above-ground part of the weed vegetation were taken lengthwise over the crop row to determine N, P and K concentrations and dry weight.

With this experimental design - apart from evaluating effects on final pod yield - based on the observations made at the end of each weed-free period or period without weed control, the pattern of growth and development of a completely weed-free crop and of a crop without weed control at all, and of the weeds, could be analysed and compared.

In Expt 2, the spatial distribution of weed growth was determined in the pod yield subplots with weed growth at harvest. A sample area of 1 x 1 m was used which was subdivided in five adjacent strips of 0.125, 0.25, 0.25, 0.25 and 0.125 m wide.

Weed species

The weed vegetation in Experiment 1 consisted mainly of *Eleusine indica* (L.) Gaertn., with *Physalis angulata* L. and *Euphorbia heterophylla* L. of secondary importance. *Eleusine indica* dominated in Experiment 2, with *Amaranthus dubius* Mart. as a secondary species. Other species were of minor or no importance.

Results and discussion

Ground-cover and leaf area index (LAI)

In Experiment 1, ground-cover of the crop, irrespective of treatment, was highest around 50 DAP (Fig. 2). It subsequently declined because of wilting and leaf-fall due to moisture shortage (Fig. 1). When, at around 90 DAP, there was again adequate moisture, the crop with weed control recovered but the crop without did not. Except at 95 DAP, no differences in ground-cover

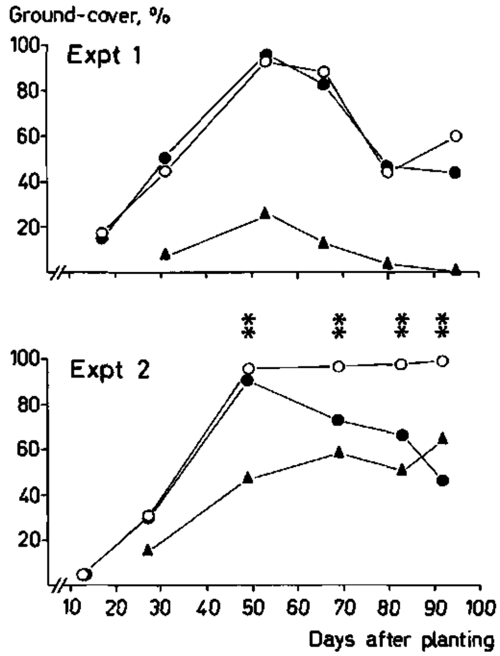

Fig. 2. Ground-cover of the crop with (o) and without (●) weed control and of the weed vegetation (▲). Following a one-sided t-test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

between the crops with and without weed control were observed. Weed growth in this experiment was not abundant, which was at least partly due to a downpour of 35 mm at 10 DAP, which destroyed many weed seedlings. Ground-cover of the weed vegetation remained low and decreased towards harvest as a result of moisture shortage.

In Experiment 2, highest values for crop ground-cover, irrespective of treatment, were also reached in about 50 DAP. Competition effects became apparent between 27 and 49 DAP. From 49 DAP onwards, the difference in crop ground-cover - and hence in light interception - between the crop with and without weed control increased. Weed growth in Experiment 2, in terms of ground-cover, was much more abundant than in Experiment 1. The weeds overgrew the crop and intermingling of crop and weed canopy resulted in supersedence and less efficient positioning of the crop leaves, which contributed to the decline in crop ground-cover.

In Experiment 1, the LAI of the crop, irrespective of treatment, increased continuously until the onset of the period of drought, when LAI values abrubtly declined due to withering and leaf-fall (Fig. 3). Treatment effects became apparent between 53 and 66 DAP and persisted until harvest (although statistically non-significant). The LAI values in Experiment 2 increased more slowly than in Experiment 1. Differences between the crop with and without weed control became evident between 27 and 49 DAP and increased with time.

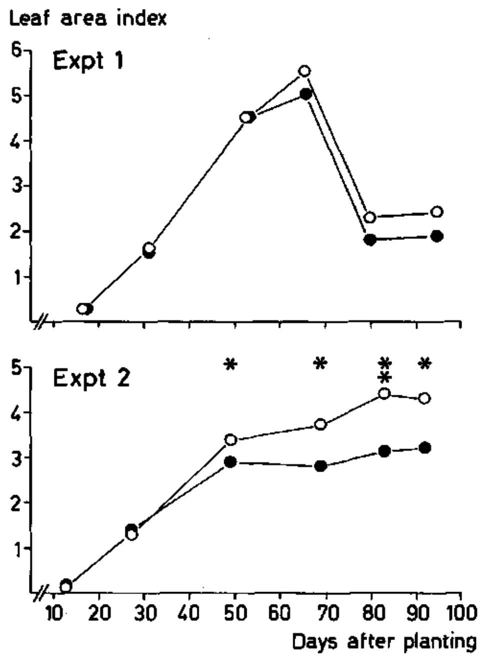

Fig. 3. Leaf area index of the crop with (o) and without (●) weed control. Following a one-sided t test a significant difference between treatments is indicated by * (p≤0.05) or ** (p≤0.01).

Dry weight and growth rate

In Experiment 1, dry weight and growth rate of the crop without weed control was not affected by weed competition until the moisture supply became limiting and dry weights and growth rates in both treatments decreased (Fig. 4, Table 2). Dry weight in both treatments was affected by leaf-fall. Pod growth during the drought period may, at least partly, have originated from the redistribution of assimilates. When the moisture supply became limiting, the weight of the weed vegetation decreased.

In Experiment 2, the lower ground-cover and LAI of the non-weeded crop clearly reduced the assimilate supply. Effects of competition on growth rate and dry weight appeared between 27 and 49 DAP and persisted until harvest. Weed competition also influenced dry matter partitioning over the various plant parts. From 49 DAP onwards, relative stem weight was higher in the non-weeded crop at the expense of leaf and pod weight. Weed dry weight in Experiment 2 increased until harvest of the crop.

Table 2. Average growth rates (kg ha^{-1} d^{-1}) of the crop (above-ground parts and pods) and pods, with and without weed control.

		Period, days after planting				
Expt 1		17–31	31–53	53–66	66–80	80–95
Crop	weed-free	56	171	152	-32	30
	no weed control	59	168	151	-79	17
Pods	weed-free	--	---	98	49	31
	no weed control	--	---	95	26	34
Expt 2		13–27	27–49	49–69	69–83	83–92
Crop	weed-free	40	144	107	82	49
	no weed control	41	122	61	66	91
Pods	weed-free	--	---	92	75	49
	no weed control	--	---	66	60	54

Initial crop growth rate was higher in Experiment 1 than in Experiment 2, which is most probably related to the 28 per cent lower average level of radiation in Experiment 2, and possibly to associated effects of lower temperature.

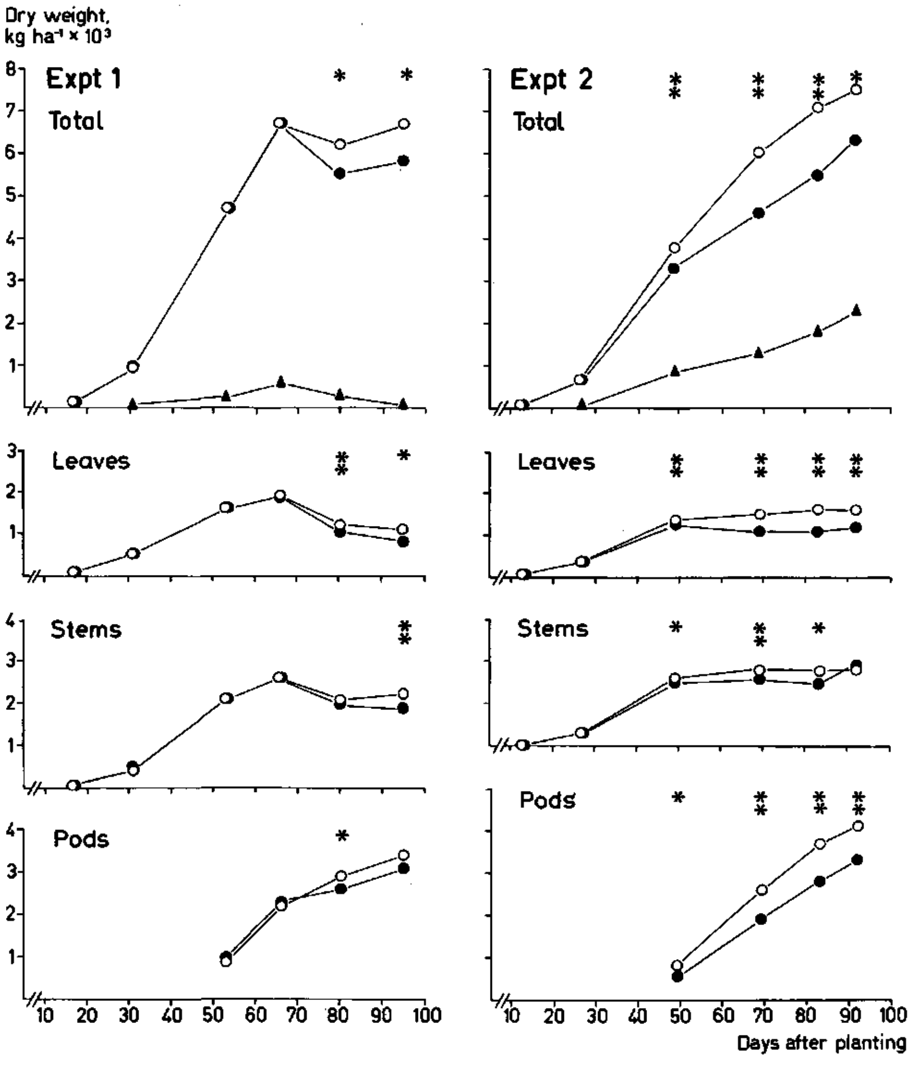

Fig. 4. Dry weight (above-ground parts and pods) of the crop with (o) and without (●) weed control and of the weed vegetation (▲, above-ground parts). Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

Development

Plant density was not influenced by treatment in either experiment, except at 31 DAP in Experiment 1 (Table 3).

In both experiments, there was a tendency towards more elongated stems in response to presence of weeds (Table 3). In Experiment 1, this reaction started between 31 and 53 DAP. With the limited moisture supply, stem-lengths decreased and differences between treatments diminished. No consistent effects were observed on the number of nodes or on the length of the internodes in this experiment.

Table 3. Development of the crop with and without weed control.

		Days after planting					
Expt 1		17	31	53	66	80	95
Number of plants	weed-free	48	50	48	49	44	48
per 3 m^2	no weed control	49	46*	48	47	46	48
Length of main	weed-free	6.8	18.1	47.9	56.0	54.4	55.3
stem, cm	no weed control	5.6	18.4	50.6**	59.1*	55.8	54.0
Number of nodes	weed-free	6	11	17	19	18+	19
on main stem	no weed control	7	11	17	20	16	18
Length of	weed-free	1.3	1.8	3.0	3.2	3.1+	3.1
internodes on	no weed control	1.0	1.9	3.2	3.1	3.7	3.2
main stem, cm							
Expt 2		13	27	49	69	83	92
Number of plants	weed-free	51	52	52	53	51	51
per 3 m^2	no weed control	52	55	51	53	53	52
Length of main	weed-free	4.9	15.6	37.7	41.8	48.4	49.2
stem, cm	no weed control	4.9	15.7	39.0	45.6**	49.1	53.4
Number of nodes	weed-free	5	9	12	13	16	17
on main stem	no weed control	6	10	12	13	15*	16
Length of	weed-free	1.1	2.0	3.4	3.4	3.2	3.1
internodes on	no weed control	1.1	1.8	3.7*	3.9*	3.6**	3.6**
main stem, cm							

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leqslant 0.05$) or ** ($p \leqslant 0.01$). (+ based on two replicates).

In Experiment 2, extra elongation of the main stem as a reaction to competition started between 27 and 49 DAP. The number of nodes tended to be lower without weed control and the length of the internodes increased. Extra elongation of the main stem and increased length of internodes as a result of competition was also noted by Hamada (1988). The extra elongation of the main stem, and probably of the branches as well, is likely to have increased the relative stem weight in the crop without weed control.

The number of branches per plant was not affected by treatment (Table 4). Reduced branching because of competition with weeds has been reported by Ishag (1971) and Hamada (1988). However, their observations refer to a 'spreading bunch' cultivar, and the reaction to competition with weeds may vary for different cultivars (Brown, 1965).

Table 4. Development of the crop with and without weed control.

		Days after planting					
Expt 1		17	31	53	66	80	95
Number of branches per plant	weed-free	3	5	5	5	5	5
	no weed control	4	5	5	5	5	5
Number of leaves per plant	weed-free	11	37	67	66	30	29
	no weed control	12	36	66	70	12**	25
Number of pods per plant	weed-free	-	-	29	31	30	31
	no weed control	-	-	31	32	25	31
Dry weight per pod, g	weed-free	-	-	0.20	0.44	0.68	0.67
	no weed control	-	-	0.21	0.48	0.68	0.66
Expt 2		13	27	49	69	83	92
Number of branches per plant	weed-free	2	4	7	7	8	7
	no weed control	2	4	7	7	7	7
Number of leaves per plant	weed-free	6	25	56	57	68	66
	no weed control	5	26	49*	41*	50**	53*
Number of pods per plant	weed-free	-	-	28	31	36	33
	no weed control	-	-	21*	26	28*	27
Dry weight per pod, g	weed-free	-	-	0.18	0.48	0.67	0.76
	no weed control	-	-	0.15	0.41**	0.59*	0.71

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

The number of leaves present per plant in Experiment 2, was significantly affected by treatment starting between 27 and 49 DAP (Table 4). From 49 to 69 DAP, the number of leaves in the non-weeded crop decreased, contributing to the decline in ground-cover and LAI in this treatment during that period (Figs. 2, 3). In Experiment 1, the number of leaves present was affected by leaf-fall due to drought, regardless of treatment (at 80 and 95 DAP only green, presumably still functioning leaves were counted). The effect, however, was more pronounced in the non-weeded crop.

Towards flowering, observations were made on the number of flowering plants and the number of inflorescences per plant. The presence of weeds had no effect on the timing of flowering or, at least initially, on the number of inflorescences per plant. The onset of flowering, defined as the moment that 50 per cent of the plants had produced at least one flower, fell between 24 and 31 DAP in Experiment 1. At 31 DAP, 86 per cent of all plants were in flower. In Experiment 2, the onset of flowering was between 23 and 26 DAP. Ninety-two per cent of the plants in both treatments were flowering by 27 DAP. Neither the percentage of flowering plants nor the number of inflorescences per plant, at 31 DAP in Experiment 1 or at 27 DAP in Experiment 2, were influenced by the treatment.

In Experiment 2, the number of pods per plant and weight per pod were lower in the absence of weed control (Table 4). Relative reduction in weight per pod, as a result of competition, decreased towards maturity. The absence of a decrease in the number of pods in the non-weeded crop with continued competition, indicates that abortion of pods did not occur. In Experiment 1, significant differences in the number of pods per plant or in weight per pod between treatments, were absent, although total dry weight of the pods was affected (Fig. 4). This discrepancy, and the low number of pods in the non-weeded crop at 80 DAP in this experiment, are perhaps partly the result of harvesting difficulties due to the fragile state of the crop under the prevailing dry conditions.

There could be several reasons for the lower number of pods per plant in the non-weeded crop. In Experiment 2 for example, the number of flowers could have been reduced. However, as generally many more flowers are produced than pods (Williams, Wilson and Bate, 1975), a smaller number of flowers can, at least partly, be compensated for by a higher percentage of flowers producing pods. This reaction was observed by Ishag (1971), who found that the absence of weed control certainly suppressed the production of flowers but, at the same time, increased the percentage of fruit set.

Hamdoun (1977) noted, that extended internodes tended to make gynophores reach the soil surface in a longer period. Such a time lag, resulting in a lower number of pods present, would also result in a lower weight per pod which, in fact, was found (Table 4). It would, however, also have resulted in a lower percentage of mature kernels and a lower shelling percentage at maturity, which was not the case. It is possible, that the longer internodes require a length of gynophores exceeding the critical maximum value, thereby reducing the number of pods, but it seems doubtful whether the stem extension observed would have such a marked effect.

The most plausible explanation for the lower number of pods per plant is that the number of flowers producing gynophores, or the number of gynophores producing pods, was affected due to reduced assimilate supply.

Nature of competitive effects

Nutrients

The amount of nutrients taken up by the weeds in Experiment 1 is small compared with the amount taken up by the crop (Table 5). Nutrient uptake of the crop in this experiment was not strongly influenced by treatment. In view of the decrease towards harvest in amount of K in the crop, irrespective of treatment, and in the weeds, the significantly lower amount of K and the lower K concentration at harvest (Table 6) are unlikely to be the result of competitive effects on uptake.

The lower P and K concentrations in the absence of weeding at 31 DAP were only temporary and may have been the result of a short period of limited moisture availability just before 31 DAP (Fig. 1). Where weeds were present, moisture stress in the uppermost soil layers may have become critical, thereby reducing nutrient uptake. Bunting and Anderson (1960) found strong negative effects of drought on the uptake of P.

In Experiment 2, the uptake of N, P and K by the crop without weed control

Table 5. Nutrient uptake (kg ha^{-1}) of the crop (above-ground parts and pods), with and without weed control, and of the weeds (above-ground parts).

		Days after planting					
Expt 1		17	31	53	66	80	95
	Crop weed-free	7	37	131	180	157	187
N	Crop no weed control	7	37	130	177	147	160*
	Weeds	-	4	5⁺	14	4	1
	Crop weed-free	0.8	3.0	10.3	13.3	12.3	14.0
P	Crop no weed control	0.7	3.0	10.0	12.7	11.7	12.7
	Weeds	-	0.6	1.2⁺	3.8	1.4	0.2
	Crop weed-free	5	33	83	107	110	100
K	Crop no weed control	5	32	91	107	93*	70**
	Weeds	-	4	9⁺	23	10	1
Expt 2		13	27	49	69	83	92
	Crop weed-free	5	28	106	173	213	260
N	Crop no weed control	5	29	91*	140**	177*	197**
	Weeds	-	5	21	29	38	38
	Crop weed-free	0.4	2.4	10.3	13.7	16.7	20.0
P	Crop no weed control	0.5	2.5	9.7	10.7**	13.7**	14.7**
	Weeds	-	0.7	3.0	3.3	4.0	5.7
	Crop weed-free	3	25	98	120	137	127
K	Crop no weed control	3	25	84*	100	93*	117
	Weeds	-	7	37	44	62	74

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$). (⁺ based on four replicates).

was considerably lower than that of the weed-free crop. However, with the exception of N and P at harvest, differences in nutrient uptake were not accompanied by lower nutrient concentrations in the non-weeded crop, indicating that nutrient uptake was not determined by availability of the nutrient, but by the demand of the crop, which is a function of its dry weight.

These results show, that despite the low soil fertility (Table 1), competition for nutrients was absent in both experiments. Several factors may have contributed to this situation:

(a) the groundnut crop fixes most of its own nitrogen, and with this capacity apparently not affected by the competition with weeds, com-

Table 6. Nutrient concentration (g kg^{-1}) of the crop (above-ground parts and pods), with and without weed control, and of the weeds (above-ground parts).

		Days after planting					
Expt 1		17	31	53	66	80	95
	Crop weed-free	38.1	38.4	28.0	27.0	25.0	28.0
N	Crop no weed control	38.4	36.4	27.7	26.7	26.6	27.9
	Weeds	----	36.0	24.5^{+}	22.1	15.6	13.5
	Crop weed-free	4.4	3.2	2.2	2.0	2.0	2.1
P	Crop no weed control	4.3	3.0*	2.2	1.9	2.1	2.2
	Weeds	---	5.9	5.9^{+}	5.4	5.3	2.8
	Crop weed-free	30.4	34.2	17.7	16.0	17.8	14.9
K	Crop no weed control	30.2	32.0*	19.4	16.2	17.0	12.1*
	Weeds	----	43.1	44.4^{+}	35.3	34.8	17.5
Expt 2		13	27	49	69	83	92
	Crop weed-free	54.8	43.8	27.8	29.2	30.2	34.3
N	Crop no weed control	55.0	43.2	27.4	30.5	32.1	31.2*
	Weeds	----	36.9	23.6	22.3	20.5	16.7
	Crop weed-free	4.8	3.7	2.7	2.3	2.3	2.6
P	Crop no weed control	5.0	3.8	2.9	2.3	2.5	2.3**
	Weeds	---	3.7	3.6	2.5	2.2	2.4
	Crop weed-free	35.8	39.2	25.8	20.4	19.1	16.9
K	Crop no weed control	35.7	37.0	25.2	21.6	16.8	18.3
	Weeds	----	51.1	40.6	33.1	36.1	32.4

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leqslant 0.05$) or ** ($p \leqslant 0.01$). ($^{+}$ based on four replicates).

petition for N was avoided;

(b) groundnuts are able to root deeply and are likely to have rooted deeper than the weeds, and as weed growth was mainly concentrated between the rows (see *Spatial distribution of weed growth*), the crop and weeds may have explored partly different soil volumes;

(c) the band-placement of the fertilizer near the crop seeds ensured better access to the nutrients applied for the crop than for the weeds.

L i g h t

In Experiment 2, weeds overgrew the crop, resulting in considerable shading of the crop, which is the reason for the extra elongation of the internodes (Table 3). At 62 DAP, average canopy height of the weed-free as well as of the non-weeded crop was between 0.4 and 0.5 m. Light measurements at this date showed that the intensity of visible light at 0.4 m above ground-level in the non-weeded crop was 72 per cent of that in the weed-free crop. At 0.3 and 0.2 m above ground-level, these percentages were 51 and 41, respectively. These data indicate strong competition for light. Shading of the crop by the weeds was not strong in Experiment 1. No light measurements were taken. Indications for shading are the extra elongated stems in the non-weeded crop at 53 and 66 DAP.

Because of the restricted height of the groundnut canopy, compared with that of the locally occurring weeds, competition for light between crop and inadequately controlled weeds will be a common phenomenon.

W a t e r

In Experiment 2, potential evapotranspiration of a weed-free crop exceeded the moisture supply between around 35 to about 65 DAP (Fig. 1). As the available moisture storage capacity of the Zanderij soils is low (Boxman et al., 1985), a contribution to available moisture from this source is not taken into account. In view of the combined ground-cover of the non-weeded crop and weeds it is likely that competition for water between the non-weeded crop and weeds occurred in this period. Evidence of water deficiency in the non-weeded crop in the period 49 to 69 DAP is found in the decrease in the number of leaves (Table 4), with the associated decrease in LAI (Fig. 3).

In Experiment 1, severe moisture stress, starting between 50 and 60 DAP, affected growth of the crop irrespective of the presence of weeds and induced differences between the treatments (Fig. 3, Table 4).

Conclusion

Under the local conditions, using current cultivation methods, groundnuts and weeds do not compete for nutrients. Competition will be for light and water, the latter depending on rainfall.

Yield

Weed-free period after planting

Keeping the crop weed-free for longer than 17 DAP in Experiment 1 did not lead to a significant increase in yield (Table 7). In Experiment 2, 13 weed-free DAP were sufficient to avoid yield losses, and in both experiments even shorter periods might have sufficed.

In neither experiment did the length of the weed-free period significantly or consistently affect plant density, 1000-seed weight, shelling percentage or percentage of sound mature kernels.

It would appear therefore that, compared with the weeding in general required after planting (see Introduction), in this case a rather short weed-free period sufficed to avoid losses. Adequate crop husbandry measures, leading to good crop establishment and growth, will have contributed to this situation.

Weed growth following the weed-free periods was assessed and found negligible. At harvest in Experiment 1, a measurable amount of weeds (0.6 kg ha^{-1}) was only found in the crop that had been kept weed-free for 31 DAP. At harvest in Experiment 2, weed growth was found only in the crop kept weed-free for 13 DAP (24 kg ha^{-1}). The crop thus had an obvious competitive advantage over the weeds after some time of weed-free conditions.

Period after planting without weed control

Competitive effects in Experiment 1 were not clearly expressed in yield

(Table 7), as they were mainly induced by the severe drought which affected crop growth in both treatments (Fig. 4). Increasing the period without weed control, however, tended to decrease yield. A substantially reduced yield was found for the crop not weeded for 80 DAP. Because the yield of the crop with no weed control at all was not so much reduced, this yield reduction must at least partly be ascribed to the inevitable disturbance of the crop

Table 7. Yield (12% moisture) and yield components with increasing periods with and without weed control.

		Period, days after planting					
Expt 1		0-17	0-31	0-53	0-66	0-80	0-94
Pod yield,	weed-free	3672 a	3578 a	3565 a	3748 a	3512 ab	3879 a
kg ha^{-1}	no weed control	3860 a	3723 a	3450 ab	3392 ab	3063 b	3452 ab
				n.s.			
Number of	weed-free	46	47	43	46	46	47
plants per 3 m^2	no weed control	46	45	45	46	46	47
				n.s.			
1000-seed	weed-free	618	597	629	603	583	608
weight, g	no weed control	626	596	621	622	624	609
				n.s.			
Shelling	weed-free	73.7	73.9	73.8	73.8	73.5	73.9
percentage	no weed control	74.0	73.6	74.6	75.2	74.4	74.7
				n.s.			
Sound mature	weed-free	87.6	86.6	89.0	83.8	80.7	87.2
kernels, %	no weed control	88.3	88.2	88.7	89.5	85.7	87.9
Expt 2		0-13	0-27	0-49	0-69	0-83	0-91
Pod yield,	weed-free	4645 a	4654 a	4576 a	4497 a	4736 a	4520 a
kg ha^{-1}	no weed control	4590 a	4628 a	4238 a	3563 b	3608 b	3544 b
				n.s.			
Number of	weed-free	53	51	50	53	52	52
plants per 3 m^2	no weed control	53	53	53	51	53	49
				n.s.			
1000-seed	weed-free	691	706	700	711	712	695
weight, g	no weed control	711	699	691	705	703	697
Shelling	weed-free	73.1 ab	73.5 ab	72.8 a	73.5 ab	73.1 ab	73.3 ab
percentage	no weed control	74.0 ab	74.0 ab	73.8 ab	74.3 abc	74.4 bc	75.7 c
Sound mature	weed-free	83.9 d	88.3 abd	86.4 ad	88.8 abc	88.3 abd	87.2 ad
kernels, %	no weed control	89.6 abc	88.4 abd	90.6 abc	89.6 abc	93.3 c	92.3 bc

For each variable, figures followed by the same letter are not significantly different ($p \leq 0.05$) according to Duncan's New Multiple Range Test. (n.s. = non-significant).

during removal of weeds at 80 DAP under the prevailing dry conditions.

Plant density, 1000-seed weight, shelling percentage, and percentage of sound mature kernels in this experiment were not influenced by the length of the period without weed control.

Prolonged periods without weed control resulted in yield reduction in Experiment 2. Yield reduction was 22 per cent without any weed control. This is low compared with losses reported in the literature (Ashrif, 1967; Goldson, 1967; Bhan et al., 1971; Schiller et al., 1976; Singh et al., 1985), which may range from 40 to 80 per cent or more. The method of cultivation, including band-placement of the fertilizers, probably increased crop competition, resulting in comparatively low yield reductions.

Delaying weed control up to 49 DAP caused a small yield reduction. Longer periods without weed control significantly reduced yields. As differences in plant density and 1000-seed weight were not significant, and shelling percentage and percentage of sound mature kernels were not negatively influenced, the main determinant of yield reduction was the lower number of pods per plant (see Table 4). Similar observations were made by Ishag (1971) and Hammerton (1976).

Whether a reduction in number of seeds per pod has contributed to the yield reduction is not known, but, in view of the relatively small reduction in weight per pod (Table 4), this seems unlikely. Moreover, this would probably have resulted in a decrease in shelling percentage, which was not found.

The number of pods per plant was mainly determined before 69 DAP (Table 4). Potential yield loss through reduction in the number of pods at 49 DAP could apparently still, although not entirely, be recovered by removal of the weeds. Removal of weeds at 69 DAP or later resulted in loss of yield.

Nevertheless, the assimilation capacity of the crop with no weed control at all was sufficient to increase shelling percentage and percentage of sound mature kernels (Table 7). Also, in view of the increase in growth rate in the non-weeded crop towards maturity (Table 2), this suggests that, in spite of the continued increase in weed weight after 69 DAP, the degree of weed competition decreased towards crop harvest, possibly as a result of maturing in the weed vegetation. The increase in shelling percentage and percentage of sound mature kernels partly compensated for the loss of yield through reduction in the number of pods.

These data indicate that the stage during which the number of pods per plant is determined, i.e. the period around 35 to 60 DAP, is critical to avoid competition with weeds. The weed-free period generally required in the tropics - four to eight weeks after planting - seems to corroborate this conclusion, as do the data of Chamblee, Thompson and Coble (1982), who worked under temperate conditions. Van Heemst (1985) stated -based on literature - that the critical period for crop-weed competition in groundnuts started immediately at planting and ended at 0.35 relative to the length of the total crop growth period. In Experiment 2 a relatively long period of absence of weed control after planting could be tolerated without yield loss. The start of the critical period for crop-weed competition will be influenced by the conditions for crop and weed establishment at planting.

Increased periods without weed control did not influence plant density. An effect on plant density will depend on weed density and type of weed growth. In the literature (Ashrif, 1967; Bhan et al., 1971; Hamdoun, 1976, 1977; Hammerton, 1976; Hamada, 1988; Hamada et al., 1988), absence of effects and negative effects are both reported.

Spatial distribution of weed growth

At harvest, weed growth in Experiment 2 was concentrated between the rows (Fig. 5). Band-placement of the fertilizer gave the crop good access to the nutrients and limited access by the weeds (Chapter VII), thus giving the crop an advantage over the weeds. Due to large seed size, groundnuts have a large seedling and can rapidly establish some ground-cover. Due to rapid canopy closure in the row, weed growth was mainly limited to the space between the rows. With soybeans grown under the same conditions, an identical spatial distribution of weed growth was found (Chapter V). With sorghum, however, more weed growth was found in the rows than between them, mainly because of a more open canopy structure (Chapter IV).

Practical implications

Because of the spatial distribution of weed growth, weed control should be concentrated on the weeds between the rows. In view of the only short weed-free period required after planting and to develop alternatives for chemical

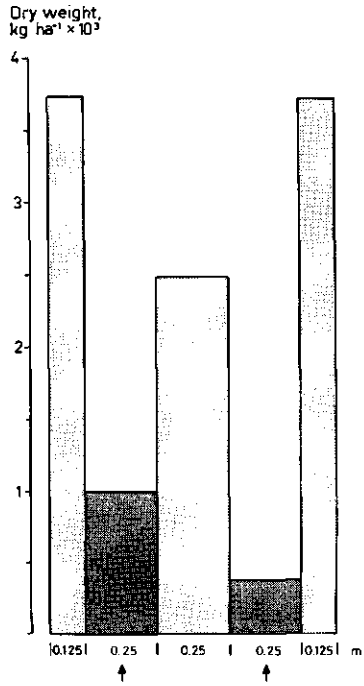

Fig. 5. Spatial distribution of uncontrolled weed growth at harvest (Expt 2; crop rows indicated by arrows).

weed control, it is considered necessary to investigate whether one or two mechanical weeding rounds, between 10 to around 20 DAP - before flowering to avoid damage to inflorescences - would be sufficient for the control of weeds. The weeding should then be done as widely as possible between the rows. Decreasing row width could further contribute to crop competitiveness (Buchanan and Hauser, 1980; Hauser and Buchanan, 1981).

Weeds in the row are difficult to control mechanically, i.e. by burying, without damaging the crop. Whether or not these weeds can be neglected without consequence must also be examined, because apart from possible competitive effects, they may interfere with harvesting operations.

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Chapter IV

EFFECTS OF COMPETITION WITH WEEDS ON GROWTH AND YIELD OF SORGHUM

Introduction

Due to a rather open canopy structure and comparatively slow establishment, sorghum (*Sorghum bicolor* (L.) Moench) can suffer severely from competition with weeds. Serious yield losses as a result of competition with weeds have been reported from many tropical and subtropical areas (Enyi, 1973; Sankaran and Mani, 1974; Subba Reddy, Venkateswarlu and Dryden, 1976; Hamdoun, 1977; Escasinas and Escalada, 1980; Upadhyay, Lomte and Shelke, 1981; Machado et al., 1985; Ndahi, 1986; Jayakumar et al., 1987).

The degree of competition, however, may depend, among other factors, on location (Singh, Singh and Singh, 1975), season (Hamdoun, 1977; Bebawi and Farah, 1981; Machado et al., 1985), cultivars (Ishag, 1968) and fertility level (Ishag, 1968; Kondap and Bathkal, 1981), whereas parasitic weeds can reduce yields more than non-parasitic weeds (Bebawi and Farah, 1981). Generally, control of weeds during the first four to about five weeks after planting is essential to avoid yield reduction. Reviews of various aspects of weed control in tropical and subtropical sorghum were given by Shetty (1979; 1979).

Sorghum is not cultivated in Suriname. Research results from the coastal plain (van Marrewijk, 1974) and from the inland region suggest, however, that fair yields may be obtained, but that variability in seasonal distribution and amount of rainfall is likely to be a major constraint to economic production.

The present chapter reports the results of two experiments in which the effects of weeds on growth and yield of sorghum in the inland Zanderij area of Suriname were studied.

Materials and methods

General

The experiments were carried out at the experimental farm Coebiti (see Chapter I), during the late long rainy season of 1982 (Expt 1) and 1983 (Expt 2). Data on rainfall during the experiments are presented in Fig. 1.

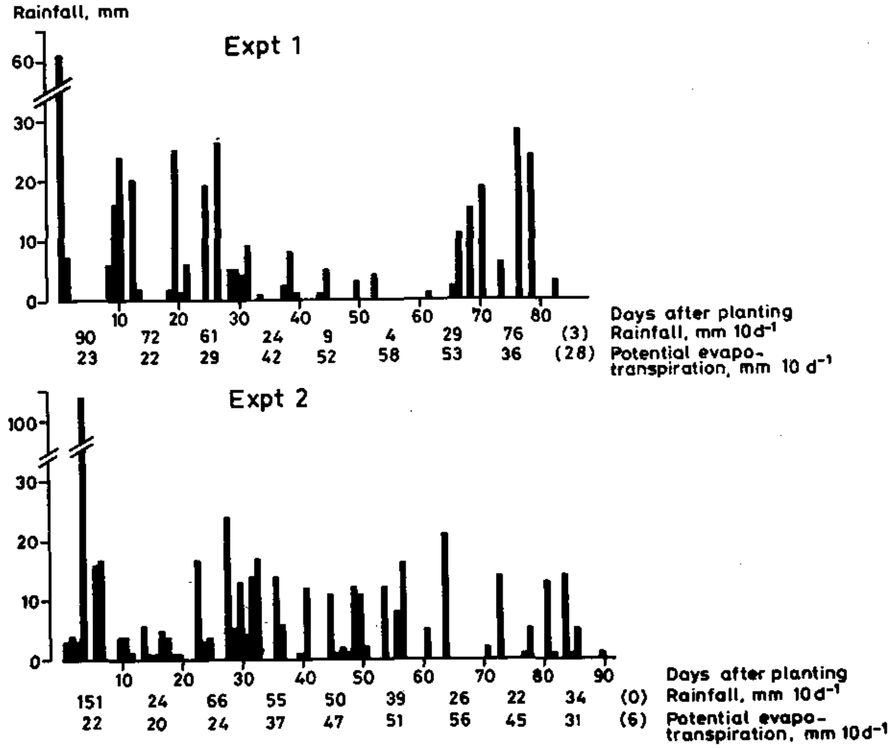

Fig. 1. Daily rainfall, and rainfall and potential evapotranspiration per ten days during the experiments.

Potential evapotranspiration of the crop was calculated in the same way as for groundnuts (Chapter III). The crop coefficient was taken as 0.45 during the first 20 DAP[1], subsequently increasing linearly to 1.00 at mid-season (45 DAP), and then decreasing linearly from 70 DAP onwards to 0.50 at harvest.

[1]DAP: Days After Planting

The soils of the experimental fields are a sandy loam (Expt 1) and a loamy sand (Expt 2) and are acid and of low fertility. They are classified as yellow kaolinitic Oxisols intergrading towards Ultisols. Soil chemical properties are given in Table 1.

Table 1. Chemical properties of the soil (0-20 cm) of the experimental fields.

	Expt 1	Expt 2
Org. C, g kg^{-1}	14.4	9.8
Org. N, g kg^{-1}	1.1	0.8
pH-KCl	4.3	4.3
pH-H_2O	-	5.2
Exch. Ca, mmol(+) kg^{-1}	13.1	15.5
Mg, mmol(+) kg^{-1}	2.4	1.7
K , mmol(+) kg^{-1}	0.9	1.3
Na, mmol(+) kg^{-1}	0.3	0.3
Al, mmol(+) kg^{-1}	5.3	4.2
ECEC, mmol(+) kg^{-1}	22.0	22.9
100 x exch. Al/ECEC	24	18
CEC, pH7, mmol(+) kg^{-1}	47.0	39.3
P-Bray I, mg kg^{-1} P	34.7	26.3

(ECEC = Effective Cation Exchange Capacity;
CEC = Cation Exchange Capacity).

Cultivation practices

Before soil preparation, the sandy loam and loamy sand were limed at the rate of 305 and 430 kg ha^{-1} Ca, respectively. Seeds were machine-planted in rows, 0.5 m apart, immediately after disc-harrowing, ploughing and harrowing. After emergence, the seedlings were thinned to an average distance of 0.15 m in the row, leading to densities of 129 000 (Expt 1, 12 DAP) and 120 000 (Expt 2, 8 DAP) plants ha^{-1}. At planting, 45 kg N, 35 kg P and 35 kg K per hectare were band-placed near the seeds. Around thirty DAP, 50 kg N and 40 kg K per hectare were side dressed near the row. The semi-dwarf, non-tillering cultivar Martin was used in both experiments. Seeds were desinfected with a fungicide in both experiments and a systemic insecticide was applied at planting. Harvesting was done manually at 88 (Expt 1) and 92 (Expt 2) DAP.

Experimental procedures

For sorghum, the experimental design was basically the same as for groundnuts (Chapter III). Plots consisted of four 11 m long rows and were subdivided into two 4 m long subplots comprising both centre rows. Yield and yield components were measured in one subplot. The following observations were made in the other subplot at the end of each weed-free period or period without weed control:

- The degree of ground-cover of crop and weed vegetation was visually estimated;
- The above-ground parts of five plants were combined and analysed for N, P and K concentrations;
- Five other plants were used to determine stem length (up to the node with the last unfolded leaf) and the number of unfolded leaves present. Total leaf-blade area of unfolded leaves of these five plants was estimated from length x largest width of each leaf-blade x 0.747 (Stickler, Wearden and Pauli, 1961) and, where necessary, corrected for the estimated fraction of dead material. Dry weight of leaf-blades, stems (including leaf-sheaths) and panicles of these plants was determined after oven-drying at 85 ^{o}C (24 h) and 105 ^{o}C (2 h);
- The remaining plants in the subplot were counted and their above-ground dry weight determined.

- In Experiment 1, in the subplots with weed growth after planting, two 0.5 x 0.8 m samples of the above-ground part of the weed vegetation were taken lengthwise over the crop row, for the determination of N, P and K concentrations and dry weight.
- In Experiment 2, one 0.5 x 0.8 m sample was taken to determine the nutrient concentrations. A sample of 1 x 1 m, subdivided in five adjacent strips of 0.125, 0.25, 0.25, 0.25 and 0.125 m wide, was taken over the crop rows to determine weed dry weight and to investigate the distribution of weed growth between and in the crop rows.

Weed species

Eleusine indica (L.) Gaertn. and *Cenchrus echinatus* L. were the dominant weeds in Experiment 1. In Experiment 2, the same weeds dominated with, locally, also *Croton hirtus* L'Hérit. as a primary species. Other species were of minor or no importance.

Results and discussion

Ground-cover and leaf area index (LAI)

In both experiments, maximum ground-cover of the weed-free crop was reached at around 55 DAP (Fig. 2). Ground-cover in Experiment 1 was lower than in Experiment 2 and it decreased rapidly in the latter part of the growing

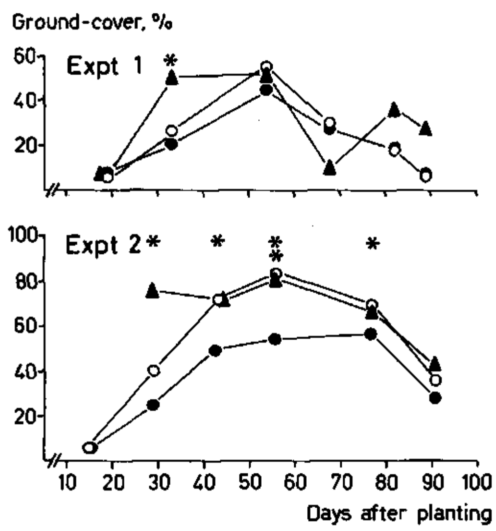

Fig. 2. Ground-cover of the crop with (o) and without (●) weed control and of the weed vegetation (▲). Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

season, because of desiccation and leaf curling due to severe drought (Fig. 1). In both experiments, ground-cover and thus light interception of the crop without weed control, were decreased already before 30 DAP. In Experiment 1, the differences between treatments later disappeared because of drought. In Experiment 2, differences in ground-cover between treatments persisted until harvest.

Weed growth, in terms of ground-cover, was more abundant in Experiment 2 than in Experiment 1. After planting in Experiment 1, weed establishment locally was concentrated in the row. As indicated by the rapid decrease in weed ground-cover after 54 DAP (Fig. 2), the weeds in Experiment 1 suffered from moisture shortage. Weed ground-cover increased again with increased moisture supply.

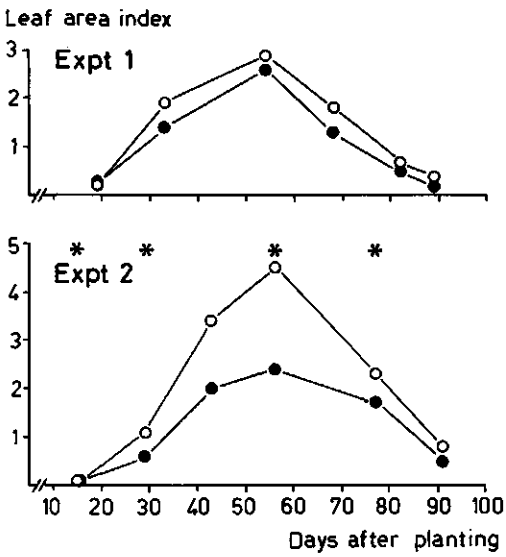

Fig. 3. Leaf area index of the crop with (o) and without (●) weed control. Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$).

LAI of the weed-free crop was highest in Experiment 2 (Fig. 3). LAI values in both experiments, for both treatments, increased until about 55 DAP when leaf production was complete, then decreased due to senescence, starting with the lower leaves. In Experiment 1, senescence was accelerated by the drought. In both experiments, the difference in LAI and hence in photosynthetic capacity between the crops with and without weed control became evident between 20 and 30 DAP. The differences lasted until harvest. Reduction of LAI in sorghum due to competition with weeds has been reported by several authors (Enyi, 1973; Sankaran and Mani, 1974; Escasinas and Escalada, 1980).

Dry weight and growth rate

The lower ground-cover and LAI of the non-weeded crop affected the assimilate supply. In both experiments, dry weight and growth rate of the crop without weed control started to lag behind those of the weeded crop between 20 to 30 DAP (Fig. 4, Table 2). Weights of all plant parts were lower in the non-weeded crop. Dry matter partitioning, however, was hardly affected by competition with weeds. In Experiment 1, the relative weights of leaves, stems and panicles were not influenced, except at the final observation date,

Table 2. Average growth rates (kg ha^{-1} d^{-1}) of the crop (above-ground parts) and panicles, with and without weed control.

		Period, days after planting				
Expt 1		19–33	33–54	54–68	68–82	82–89
Crop	weed-free	127	205	133	-2	63
	no weed control	79	185	85	13	53
Panicles	weed-free	---	---	155	40	58
	no weed control	---	---	95	33	48
Expt 2		15–29	29–43	43–56	56–77	77–91
Crop	weed-free	60	173	235	148	100
	no weed control	40	100	135	110	90
Panicles	weed-free	--	---	---	143	113
	no weed control	--	---	---	95	90

when percentage stem weight of the crop without weed control was significantly higher as compared to that of the weed-free crop. In Experiment 2, distribution of dry matter over the plant parts differed only at 29 DAP, with a lower relative leaf weight and a higher relative stem weight in the non-weeded crop. Evidently, as the result of moisture shortage, the rate of dry

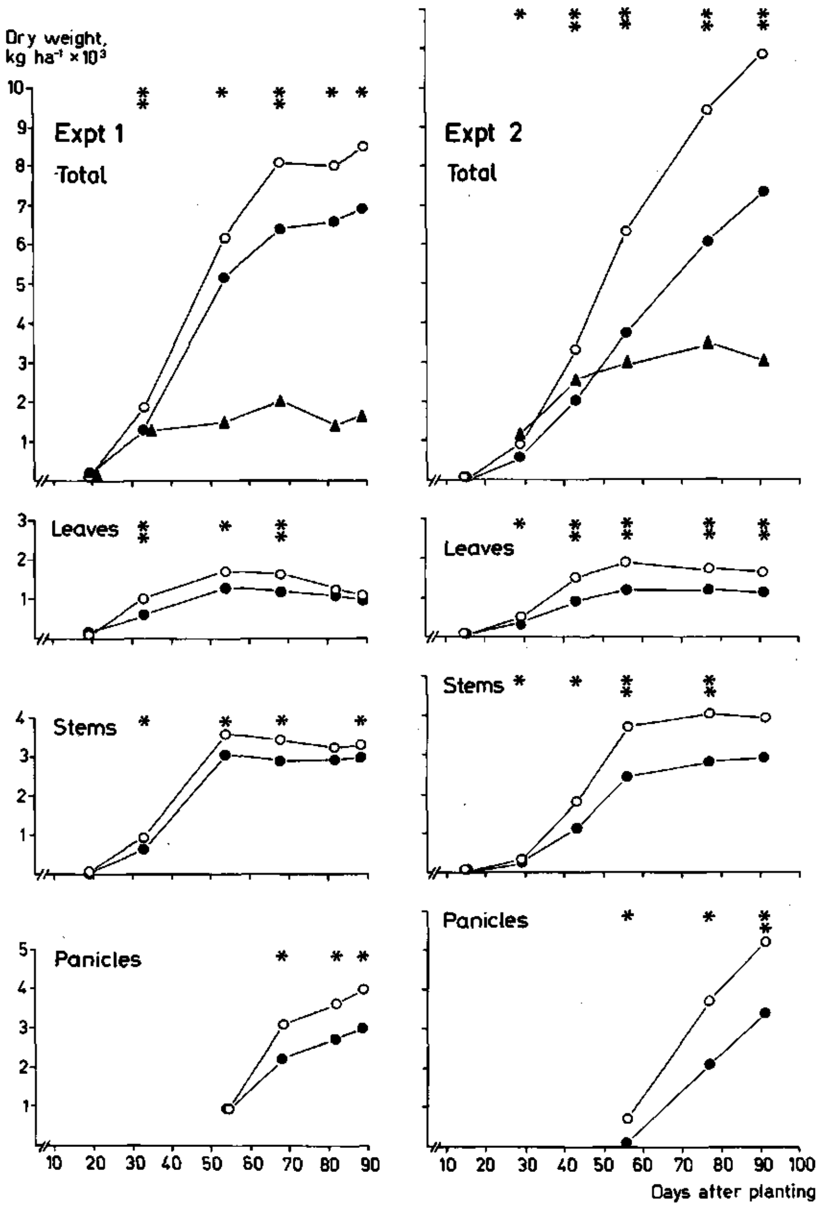

Fig. 4. Dry weight (above-ground parts) of the crop with (o) and without (●) weed control and of the weed vegetation (▲, above-ground parts). Following a one-sided t test a significant difference between treatments is indicated by * (p≤0.05) or ** (p≤0.01).

matter accumulation in Experiment 1, especially that of the non-weeded crop, declined after 54 DAP. Although moisture was adequate again around 70 DAP, growth rates, irrespective of treatment, declined even more than before, suggesting that some irreversible damage had been incurred during the severe drought.

Growth of the panicles during the period 68 to 83 DAP is likely to have been largely due to the redistribution of assimilates. This process was apparently stronger in the weed-free crop.

As no severe drought occurred in Experiment 2, growth was more continuous than in Experiment 1.

Weed growth in Experiment 2 was vigorous, and weight of the weeds initially increased more rapidly than that of the crop without weed control. In Experiment 1, weed growth developed less rapidly than in Experiment 2, and like the crop, growth of the weeds later suffered from the drought.

Development

Plant density was not affected by treatment in either experiment (Table 3). In Experiment 1, stem length of the crop without weed control first exceeded that of the weed-free crop (Table 3). Later on, due to the drought, stem length decreased and differences in stem length between the weed-free and non-weeded crop became less clear.

In Experiment 2, stem growth of the crop without weed control was retarded compared to the weed-free crop, starting between 15 and 29 DAP, and this persisted until harvest. Reduced stem length due to competition with weeds is a common phenomenon in sorghum (Enyi, 1973; Escasinas and Escalada, 1980; Bebawi and Farah, 1981; Rathore et al., 1985). Sankaran and Mani (1974), however, also noted an increase in plant height in one of two seasons.

Starting between 20 to 30 DAP, absence of weed control resulted in a reduced number of leaves present in both experiments. Effects, which were more pronounced in Experiment 1 than in Experiment 2, persisted until harvest. This lower number of leaves contributed to the reduced ground-cover and LAI of the non-weeded crop (Figs. 2 and 3).

Competition with weeds delayed panicle emergence in Experiment 2. At 56

Table 3. Development of the crop with and without weed control.

		Days after planting					
Expt 1		19	33	54	68	82	89
Number of plants	weed-free	49	51	50	56	46	51
per 4 m^2	no weed control	55	52	51	53	52	52
Length of	weed-free	11	40	102	101	107	112
stem, cm	no weed control	14*	44	116	104	106	103
Number of leaves	weed-free	5	8	10	11	10	10
per plant	no weed control	5	7	10	9*	9**	8**
Expt 2		15	29	43	56	77	91
Number of plants	weed-free	49	49	48	47	46	41
per 4 m^2	no weed control	49	53	50	49	46	47
Length of	weed-free	7	28	67	123	122	120
stem, cm	no weed control	7	26*	60	103**	107	110
Number of leaves	weed-free	3	8	9	12	12	12
per plant	no weed control	3	5**	9	11**	12	11*

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

DAP, the non-weeded crop had a lower number of plants with panicles compared with the weed-free crop. This difference had disappeared at the next sampling date. No conclusions could be drawn in Experiment 1. Delayed panicle emergence had also been found by Enyi (1973).

Nature of competitive effects

L i g h t

In both experiments, the weeds shaded the crop, especially the lower leaves. The weeds never overgrew the crop and shading of the uppermost leaves was only limited. In Experiment 1, shading is likely to have resulted in the extra elongated stems observed in the non-weeded crop (Table 2). The effect was absent in Experiment 2. Shading here apparently did not result in extra stem elongation, or the effect was offset by other competitive effects. Despite the increased stem length observed in Experiment 1, it would appear that because of the rather open canopy structure of the sorghum crop, allowing deep penetration of light, and the fact that weeds did not overgrow the crop, competition for light did not play a significant role. Because the locally occurring weeds are usually shorter than the sorghum, it is unlikely that sorghum suffers from serious competition for light with weeds. Under different conditions, however, competition for light may play a significant role (Graham, Steiner and Wiese, 1988).

N u t r i e n t s

During the first 30 DAP in both experiments, more nutrients were taken up by the weeds than by the non-weeded crop (Table 4). Comparable observations were made by Sankaran and Mani (1972) and Jayakumar et al. (1987).

In Experiment 2, accumulation of N and K by the weeds almost always exceeded that of the crop without weed control throughout the crop growth cycle. In both experiments, uptake of nutrients by the non-weeded crop was considerably lower than that of the weed-free crop. The lower nutrient concentrations in the non-weeded crop (Table 5) indicate that nutrient supply to the crop was reduced because of the presence of weeds. Competitive effects on nutrient concentration were found as early as 15 DAP.

In view of the reduction of nutrient concentrations at around four weeks after planting, it would appear that it was especially N that was competed for initially. This agrees with the observation that weeds - especially a vegetation dominated by *Eleusine indica* - respond particularly well to N (Chapter VI), and this is corroborated by the fact that in both experiments, around four weeks after planting, the non-weeded crop showed signs of yellowing due to N deficiency. Figures of Table 5 indicate that competition for P appears to have ceased in the later part of the growing season.

At 68 DAP in Experiment 1, the differences in nutrient concentration between the crop with and without weed control had been reduced. As nutrient uptake from the upper soil layers was restricted because of the severe drought, the higher growth rate of the weed-free crop possibly resulted in greater dilution of nutrients in this crop and, consequently, in smaller differences in concentrations between treatments.

More weed growth was found in the rows than between them (see *Spatial distribution of weed growth*), so that to a large extent the weeds explored the same soil volume as the crop and therefore competed for the nutrients applied. This explains why such a pronounced competition for nutrients was found.

From the evidence presented in this section, it may be concluded, that under local conditions competition for nutrients between sorghum and weeds is a common phenomenon.

Table 4. Nutrient uptake (kg ha^{-1}) of the crop (above-ground parts), with and without weed control, and of the weeds (above-ground parts).

		Days after planting					
Expt 1		19	33	54	68	82	89
	Crop weed-free	6	41	85	92	90	99
N	Crop no weed control	7	17**	65*	69*	69**	72**
	Weeds	5	34	32	35	25	28
	Crop weed-free	5.5	5.5	13.7	14.7	15.5	16.8
P	Crop no weed control	5.8	3.1**	10.8*	11.4*	13.0	13.7*
	Weeds	0.5	3.5	2.5	3.0	2.5	2.8
	Crop weed-free	6	88	153	140	128	137
K	Crop no weed control	8	49**	101**	109**	88**	94**
	Weeds	6	59	68	69	42	52
Expt 2		15	29	43	56	77	91
	Crop weed-free	1	30	77	85	92	108+
N	Crop no weed control	1	12**	36**	36**	48**	66*+
	Weeds	--	32	50	57	50	42
	Crop weed-free	0.1	3.5	12.2	17.3	23.2	27.4+
P	Crop no weed control	0.1	2.1**	6.7**	10.5**	14.9**	17.5*+
	Weeds	--	5.0	6.0	8.0	7.0	7.8
	Crop weed free	1	39	110	141	135	141+
K	Crop no weed control	1	23*	62**	74**	73**	81**+
	Weeds	--	56	91	123	98	99

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$). (+ based on four replicates).

Table 5. Nutrient concentration (g kg^{-1}) of the crop (above-ground parts), with and without weed control, and of the weeds (above-ground parts).

		Days after planting					
Expt 1		19	33	54	68	82	89
N	Crop weed-free	45.7	21.9	13.6	11.4	11.2	11.6
	Crop no weed control	39.2**	13.7**	12.5**	10.9	10.6	10.4*
	Weeds	45.7	25.1	21.7	18.1	18.4	18.9
P	Crop weed-free	4.3	2.9	2.2	1.8	1.9	2.0
	Crop no weed control	3.5*	2.4*	2.1	1.8	2.0	2.0
	Weeds	4.4	2.5	1.7	1.5	1.7	1.8
K	Crop weed-free	50.4	46.8	24.5	17.4	15.9	16.1
	Crop no weed control	45.9*	38.4**	19.7**	17.1	13.3*	13.6*
	Weeds	58.0	45.1	44.6	36.0	29.9	31.6
Expt 2		15	29	43	56	77	91
N	Crop weed-free	48.3	35.0	23.6	13.3	9.7	10.0+
	Crop no weed control	43.5**	19.7**	17.8**	9.6*	8.0**	9.1+
	Weeds	----	28.2	25.2	18.9	16.1	12.5
P	Crop weed-free	6.5	4.1	3.7	2.7	2.5	2.5+
	Crop no weed control	5.8	3.5	3.3*	2.8	2.5	2.5+
	Weeds	---	4.4	3.0	2.6	2.2	2.3
K	Crop weed-free	50.9	44.5	33.4	22.3	14.3	13.1+
	Crop no weed control	46.1**	38.8*	31.4	19.6*	12.1*	11.3+
	Weeds	----	49.7	45.8	40.5	31.2	29.0

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$). (+ based on four replicates).

W a t e r

The data shown in Fig. 1 indicate that, not taking into account the - potentially rather limited (Boxman et al., 1985) - amount of soil-available water, in Experiment 1 rainfall in the period 30 to around 70 DAP was inadequate to support potential evapotranspiration of a (weed-free) crop. Desiccation and curling of leaves, irrespective of treatment, indicated severe moisture stress for the crop around 54 DAP. Moisture stress is further indicated by the reduction in stem length in the non-weeded crop in the period

54 to 68 DAP (Table 3). In view of these observations, competition for water between the non-weeded crop and weeds in the period 30 to around 70 DAP seems obvious.

In Experiment 2, there were no symptoms of moisture stress observed in the field. Potential evapotranspiration of a weed-free crop exceeded rainfall in the period around 50 to 80 DAP and competition for water between the non-weeded crop and weeds may have occurred in this period. Chauduri and Kanemasu (1982) found water stress to affect plant height in sorghum. The reduced stem length of the non-weeded crop in this experiment (Table 3), could therefore perhaps point at competition for water.

Conclusion

Under the local conditions, competition for both nutrients and water, the latter depending on the rainfall, plays the major role in the competition between sorghum and weeds. Competition for light seems unlikely.

Yield

Weed-free period after planting

Due to the severe impact of drought yields in Experiment 1 were lower than in Experiment 2 (Table 6). A weed-free period of 19 DAP in Experiment 1 was sufficient to avoid yield losses due to competition. In Experiment 2, a weed-free period of 22 DAP had the same result, and even shorter weed-free periods might have had the same effect.

Weed growth following a short weed-free period after planting, was low. Only the two shortest weed-free periods after planting had measurable amounts of weeds at harvest: 190 and 10 kg ha^{-1} in Experiment 1, and 212 and 44 kg ha^{-1} in Experiment 2. Weed growth is thus negligible if the crop is kept weed-free for around 30 DAP.

Plant density, number of panicles, 1000-grain weight, or number of grains per panicle were not influenced by the length of the weed-free period after

Table 6. Yield (12% moisture) and yield components with increasing periods with and without weed control.

		Period, days after planting					
Expt 1		0-19	0-33	0-54	0-68	0-82	0-88
Grain yield,	weed-free	2773 ab	2823 ab	2891 ab	2903 ab	2824 ab	2786 ab
kg ha^{-1}	no weed control	2870 ab	3177 b	2643 ab	2394 ac	2332 ac	1887 c
					n.s.		
Number of	weed-free	51	47	50	50	48	50
plants per 4 m^2	no weed control	51	50	48	52	51	52
					n.s.		
Number of pa-	weed-free	48	43	48	49	45	46
nicles per 4 m^2	no weed control	46	51	46	47	48	46
Number of grains	weed-free	1601 ab	1702 a	1658 a	1643 a	1744 a	1611 ab
per panicle	no weed control	1732 a	1476 abc	1367 bcd	1370 bcd	1292 cd	1112 d
1000-grain	weed-free	14.5 a	15.5 ab	14.5 a	14.6 a	14.6 a	15.1 a
weight, g	no weed control	14.3 a	16.9 b	17.0 b	14.8 a	15.2 a	15.0 a
Expt 2		0-15	0-29	0-43	0-56	0-77	0-92
Grain yield,	weed-free	3964^{+}a	4043 a	4105 a	4310 a	3642 ac	4345 a
kg ha^{-1}	no weed control	4195 a	3987 a	3152 bc	3055 bc	2863 b	2627 b
					n.s.		
Number of	weed-free	44^{+}	46	45	49	47	47
plants per 4 m^2	no weed control	47	46	45	45	45	44
					n.s.		
Number of pa-	weed-free	44^{+}	48	47	47	45	47
nicles per 4 m^2	no weed control	46	46	47	44	44	43
Number of grains	weed-free	2047^{+}a	1912 a	1982 a	2112 a	1778 a	2059 a
per panicle	no weed control	2125 a	2005 a	1351 b	1391 b	1277 b	1252 b
1000-grain	weed-free	17.9^{+}a	17.5 a	17.9 a	17.5 a	18.1 ac	17.9 a
weight, g	no weed control	17.6 a	17.3 a	20.2 b	19.7 b	20.1 b	19.3 bc

For each variable, figures followed by the same letter are not significantly different ($p \leqslant 0.05$) according to Duncan's New Multiple Range Test. $^{+}$weed-free 0-22 DAP. (n.s. = non-significant).

planting.

In both experiments, damage to the crop by stem borers was observed. At harvest in Experiment 2 on average the crop with weed-free periods after planting appeared more affected than the crop with periods without weed-control after planting.

Period after planting without weed control

Periods without weed control of 54 DAP or longer, caused yield reductions in Experiment 1, reaching a maximum of 32 per cent in the case of no weed control at all (Table 6). The absence of weed control for 43 DAP or longer reduced yields in Experiment 2, reaching a maximum of 40 per cent where there was no weed control at all. These maximum yield losses are comparable to the yield losses of around 40 to 50 per cent commonly mentioned in the literature (Escasinas and Escalada, 1980; Kondap and Bathkal, 1981; Upadhyay et al., 1981). Yield loss can be higher, however. Enyi (1973) and Ndahi (1986) reported potential yield losses of around 85 per cent.

In neither experiment were yield reductions observed when weeds were removed at approximately 30 DAP, despite the observed reduction in growth of the crop without weed control at that time (Figs. 3 and 4), indicating that the affected crop at that stage still had the same yield potential as the weed-free one. The observed yield reduction was primarily caused by a reduction in the number of grains per panicle. Varying the period without weed control had no significant effect on plant density or on the number of panicles, while the 1000-grain weight was not negatively influenced.

Hamdoun (1977) found a negative effect of weed growth on plant density in one of three seasons. An effect of weed growth on plant density will mainly be due to smothering of crop plants, which depends on the vigour and type of weed growth.

The number of grains per panicle was affected between 19 and 54 DAP in Experiment 1, and between 29 and 43 DAP in Experiment 2. This suggests, that around 30 to 40 DAP the final number of florets was established, determining the potential number of grains per mature panicle. Once the number of grains per panicle has been determined, it cannot be corrected by removing the competition (Table 6). The relatively small effect on the number of grains per panicle with continued competition indicates, that reduced floret fertilization or spikelet abortion played no major role in yield reduction. The difference in the number of grains per panicle, observed between the treatments 82 and 88 DAP without weed control in Experiment 1, is difficult to explain.

In Experiment 2, with removal of weeds after 29 DAP, weight per grain increased (Table 6). However, also with continued presence of weeds up to harvest, assimilate supply was sufficient to increase the weight per grain. This indicates that the degree of weed competition decreased towards crop harvest, presumably as a result of maturing of the weeds. In Experiment 1, increased weight per grain was also apparent in the treatments with weed removal at 33 and 54 DAP, but with weed removal at later dates, or not at all, a possible increase in weight per seed was presumably offset by effects of the severe drought. A lower number of grains per panicle, together with a higher weight per seed, as a result of competition with weeds, has also been observed by Escasinas and Escalada (1980). Drought stress during early panicle development produced similar results (Manjarrez-Sandoval et al., 1989).

The increase in weight per grain partly compensated for the lower number of grains. In Experiment 1, in the case of competition up to 33 DAP, the potential yield reduction through the reduced number of grains per panicle was even more than compensated for by increased weight per grain. It can be speculated whether this crop perhaps better withstood the drought, or utilized the second fertilizer application more efficiently than the entirely weed-free crop.

The data presented in Table 6 indicate that absence of competition with weeds during the period of floret establishment, is critical to avoid yield reduction in sorghum. In the experiments presented here, this period was around 30 to 40 DAP. Although the frequent absence of an indication of the length of the crop growth cycle in the literature hampers comparison with our results, the weeding after planting usually required to avoid yield losses suggest that the period of floret establishment is generally critical, both under tropical and temperate (Burnside and Wicks, 1967; 1969) conditions. Van Heemst (1985) - based mainly on literature from North America - calculated the critical period for crop-weed competition in sorghum as from 0.15 to 0.21 of the total length of the crop growth period.

Spatial distribution of weed growth

At 29 DAP in Experiment 2, more weed growth was found in the rows than between them, a pattern that persisted until harvest (Table 7). Sorghum is not a very competitive crop as it is slow to establish due to its small seed size, and because of its rather open canopy structure which only shades weed growth to a limited degree. In spite of the advantage to the crop of good access to applied nutrients, these crop characteristics allow weed growth to concentrate on the fertilizer placed near the plant rows (see Chapter VII). The low soil fertility (Table 1) will have accentuated this spatial distribution of weed growth. For groundnuts and soybeans grown under the same conditions, the spatial distribution of weed growth was different, i.e. more weed growth between the rows than in them, mainly due to the different canopy structure (Chapters III and V).

Table 7. Amount of weeds (dry weight, kg ha^{-1}) between and in the rows (Expt 2).

	Days after planting				
	29	43	56	77	91
Between the rows	1090	2132	2450	2724	2460
In the rows	1393*	2920**	3465**	4054*	3476*

Following a one-sided t test a significant difference is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

Practical implications

Under the local conditions, using current cultivation methods, sorghum needs only a rather short weed-free period after planting to avoid yield losses, while control of weeds should especially focus on weeds in the row. Importance of weeding in the row in sorghum was also demonstrated by Klaij (1983) and Korwar and Friesen (1985). To reduce the dependence on chemical weed control or to reduce herbicide use, it is necessary to investigate whether one or two mechanical weeding rounds between 10 and 25 DAP would be sufficient to prevent yield reduction. Use could be made of the type of device described by Terpstra and Kouwenhoven (1981), that uproots the weeds between the rows and buries them in the row. Also, a combination of chemical control in the row with mechanical control of weeds between the rows (Korwar and Friesen, 1985), or the use of smother crops for weed control between the rows, and for additional product (Rao and Shetty, 1981; Abraham and

Singh, 1984), should be considered. Finally, decreasing planting distance in the row could add to crop competitiveness.

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Chapter V

EFFECTS OF COMPETITION WITH WEEDS ON GROWTH AND YIELD OF SOYBEANS

Introduction

Average soybean (*Glycine max* (L.) Merr.) yields in many tropical countries are low (FAO, 1986). Among other reasons, data in the literature indicate that substantial yield losses can occur due to inadequate weed control (Waranyuwat and Kotama, 1973; Bhan, Megh Singh and Maurya, 1974; Sistachs and Leon, 1975; Chew, Chew and Abdul Razak, 1976; Gurnah, 1976; Blanco, Oliveira and Araujo, 1978; Krishnamurthy et al., 1981; Ar, Sudiman and Noor, 1982; Eissner et al., 1984; Fageiry, 1987).

The degree of competition between crop and weeds is, among other factors, influenced by plant density (Nangju, 1980), row spacing (Hammerton, 1972; Nangju, 1980), cultivar (Nangju, 1980; Durigan et al., 1983), season (Thomas and van Lindert, 1980) and soil moisture conditions (Watanabe, Nordsomboon and Sasiprapa, 1981), while the presence of weeds may affect seed quality (Dhingra and da Silva, 1978; Nangju, 1980). Eiszner, Franke and Pohlan (1986) listed many crop characteristics that were influenced by competition with weeds.

In general, weed control during the first four to about six or seven weeks after planting is required to avoid yield losses.

Hammerton (1976) and Moody (1979) have presented reviews of effects of weeds and weed control in tropical soybeans. An account on weed control in soybeans in the Philippines was given by Moody, Robles and Floresca (1986).

In Suriname, soybeans are cultivated on a small scale only. Experiments with mechanical cultivation on clay soils of the coastal plain are described by van der Meulen (1955) and Fortanier (1962). In these experiments, satisfactory yields were obtained but problems, mainly related to climate and soils, remained. In recent years, interest has developed in the cultivation of the crop on sandy loam soils in the inland region of Suriname.

In this chapter, the results of two experiments on the effects of weeds on growth and yield of soybeans in the inland Zanderij area of Suriname are presented.

Materials and methods

General

The experiments were carried out at the experimental farm Coebiti (see Chapter I), during the late long rainy season of 1982 on a loamy sand to sandy loam soil (Expt 1) and during the short rainy season of 1982-83 on a sandy loam soil (Expt 2). The soils are acid and of low fertility and belong to the yellow kaolinitic Oxisols intergrading towards Ultisols. Soil chemical properties are given in Table 1.

Data on rainfall during the experiments are presented in Fig. 1. Potential evapotranspiration of the crop was calculated in the same way as for groundnuts (Chapter III). The crop coefficient was taken as 0.45 during

Table 1. Chemical properties of the soil (0-20 cm) of the experimental fields.

	Expt 1	Expt 2
Org. C, g kg^{-1}	10.7	11.6
Org. N, g kg^{-1}	0.7	0.9
pH-KCl	4.4	4.1
pH-H_2O	-	5.2
Exch. Ca, mmol(+) kg^{-1}	9.0	7.9
Mg, mmol(+) kg^{-1}	0.8	4.1
K , mmol(+) kg^{-1}	1.0	2.2
Na, mmol(+) kg^{-1}	0.3	0.9
Al, mmol(+) kg^{-1}	3.3	6.6
ECEC, mmol(+) kg^{-1}	14.3	21.8
100 x exch. Al/ECEC	23	30
CEC, pH7, mmol(+) kg^{-1}	27.0	34.0
P-Bray I, mg kg^{-1} P	30.4	25.7

(ECEC = Effective Cation Exchange Capacity;

CEC = Cation Exchange Capacity).

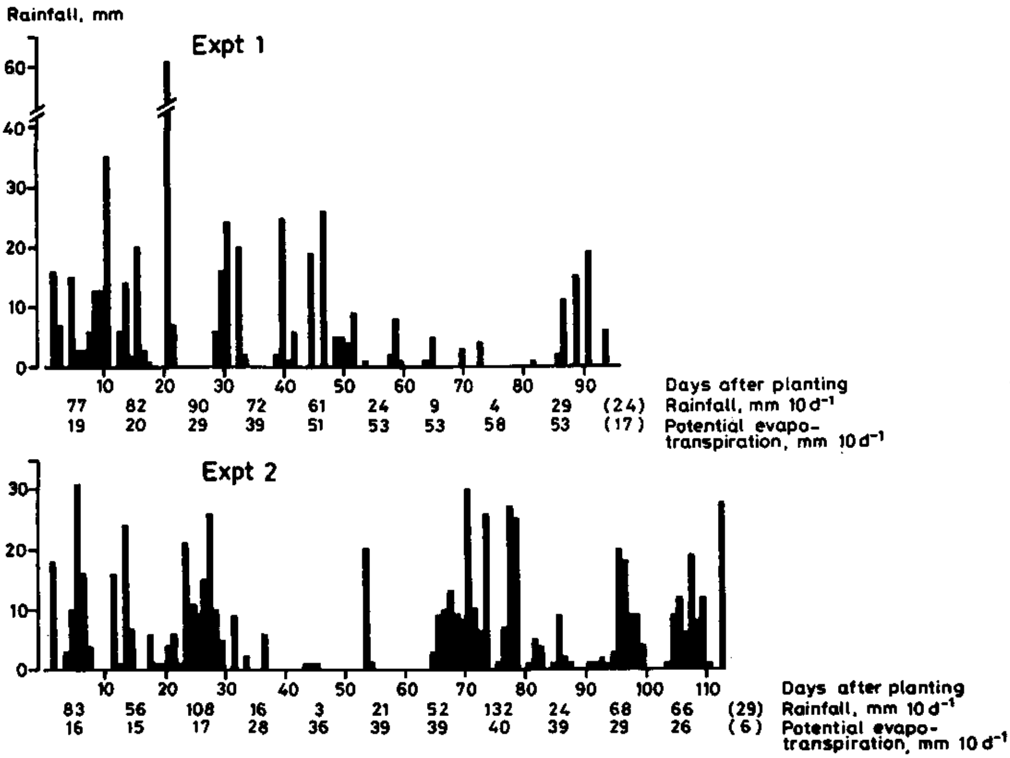

Fig. 1. Daily rainfall, and rainfall and potential evapotranspiration per ten days during the experiments.

the first 20 DAP[1], subsequently increasing linearly to 1.00 at mid-season (45 DAP), and then decreasing linearly from 90 DAP onwards to 0.45 at harvest.

Cultivation practices

Before soil preparation, the experimental sites were limed at the rate of 365 (Expt 1) and 400 kg ha^{-1} Ca (Expt 2). Seeds were machine-planted in rows, 0.5 m apart, at 7 (Expt 1) or 6 (Expt 2) cm in the row, immediately

[1]DAP: Days After Planting

after disc-harrowing, ploughing and harrowing. Open plant spaces were re-planted at emergence. Seedlings were thinned where necessary to an average distance of 0.10 m in the row, leading to densities of 148 000 (Expt 1, 25 DAP) and 186 500 (Expt 2, 13 DAP) plants ha^{-1}. At planting, *Rhizobium* inoculum was given and 18 kg N, 36 kg P and 36 kg K per hectare were band-placed near the seeds. Around 30 DAP, 40 kg ha^{-1} K was surface banded near the row. The determinate cultivar Jupiter was used in both experiments. Seeds were desinfected with a fungicide in both experiments. In Experiment 2, insecticide was routinely applied against foliage-feeding insects. Harvesting was done manually at 96 (Expt 1) and 113 (Expt 2) DAP.

Experimental procedures

For soybeans the experimental design was basically the same as for groundnuts (Chapter III), except that for the second experiment there were two series of seven instead of six treatments.

Plots consisted of four 7.5 m long rows and were subdivided into two 3 m long subplots comprising both centre rows. At maturity, final seed yield was measured in one subplot. In the other subplot at the end of each weed-free period or period without weed control, the following observations were made:

- The degree of ground-cover of the crop and weed vegetation was visually estimated;
- The above-ground parts of five plants were combined and analysed for N, P and K concentrations;
- Five other plants were used to determine main stem length (up to the node with the last fully unfolded leaf), the number of nodes on the main stem, and the number of branches, inflorescences and pods present. Total leaf area of these five plants was estimated using the punch disc method, punching, as a rule, six leaflets per plant twice. Dry weight of leaflets, stems (including leaf-stalks) and pods of these plants was determined after oven-drying at 85 °C (24 h) and 105 °C (2 h);
- The remaining plants in the subplot were counted and their above-ground dry weight established.

Observations on dry weight and nutrient concentrations of the weed vegetation were carried out in a similar way as described for the experiments with groundnuts (Chapter III). In Experiment 1 at harvest, no reliable observations on dry weight or nutrient concentrations of the crop could be made because of soil particles which had splashed onto the crop and adhered to it.

Weed species

Eleusine indica (L.) Gaertn. was the dominant weed species in Experiment 1, with *Euphorbia heterophylla* L. and *Physalis angulata* L. of secondary importance. The main weeds in Experiment 2 were *Digitaria* spp., *Cenchrus echinatus* L., and *Eleusine indica*. Other species were of minor or no importance.

Results and discussion

Ground-cover and leaf area index (LAI)

In both experiments, ground-cover, irrespective of treatment, reached its maximum around 60 DAP (Fig. 2). In Experiment 1, ground-cover declined sharply thereafter, irrespective of treatment, because of wilting and leaf-fall as a result of drought (Fig. 1). Weeds started to affect ground-cover and hence light interception, between 25 and 46 DAP. This effect persisted until harvest. In Experiment 2, no substantial differences in ground-cover between the crop with and without weed control were observed.

Weed ground-cover in Experiment 1 declined in the latter part of the growing season due to moisture shortage. In Experiment 2 in particular, weed ground-cover increased following reduced crop competition, because of leaf-fall of the crop towards maturity.

Maximum LAI values in both experiments were reached around 50 to 60 DAP (Fig. 3). Starting between 25 and 46 DAP in Experiment 1, the LAI of the non-weeded crop was considerably lower than that of the weed-free crop, thus reducing the photosynthetic capacity of the crop. In this experiment,

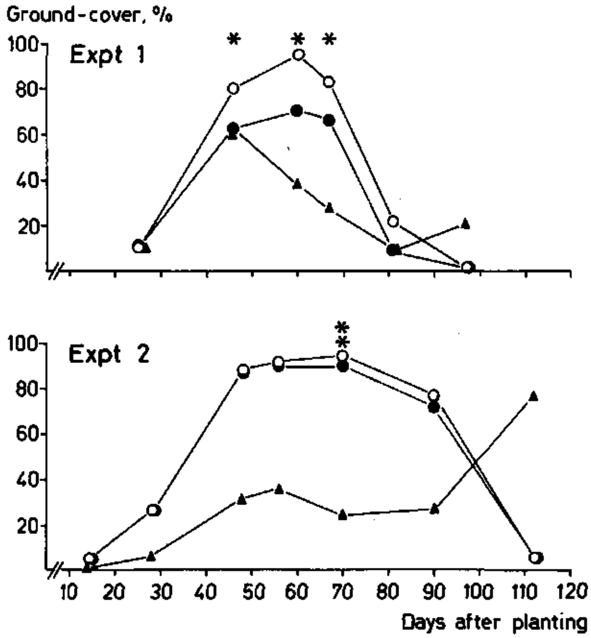

Fig. 2. Ground-cover of the crop with (o) and without (●) weed control and of the weed vegetation (▲). Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

the severe drought later accelerated the decline in LAI, irrespective of treatment, because of leaf-fall resulting from the drought.

Dry weight and growth rate

In Experiment 1, the reduced ground-cover and LAI of the crop without weed control resulted in a reduced assimilate supply. In this experiment, growth rate and dry weight of the non-weeded crop were affected between 25 and 46 DAP (Table 2, Fig. 4). Weight of the stems was affected first. Relative stem weight was significantly lower at 46 DAP only, coupled with a higher relative leaf weight. No differences in relative weights of the various plant parts were observed on the other sampling dates. From around 60 DAP

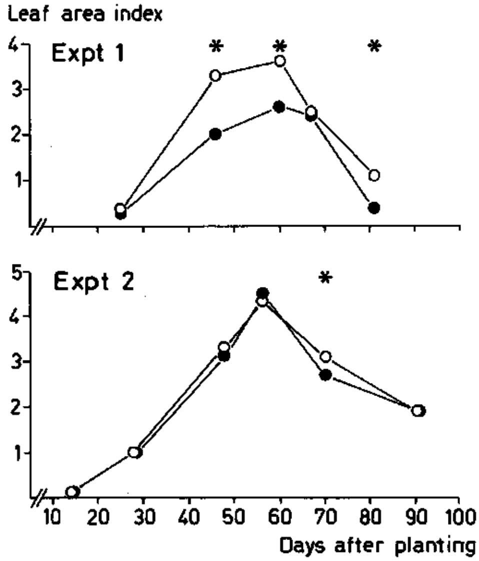

Fig. 3. Leaf area index of the crop with (o) and without (●) weed control. Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$).

Table 2. Average growth rates (kg ha^{-1} d^{-1}) of the crop (above-ground parts) and pods, with and without weed control.

		Period, days after planting					
Expt 1			25–46	46–60	60–67	67–81	
Crop	weed-free		77	141	91	-49	
	no weed control		65	110	0.8	3	
Pods	weed-free		--	---	81	32	
	no weed control		--	---	44	43	
Expt 2		14–28	28–48	48–56	56–70	70–90	90–112
Crop	weed-free	23	83	118	127	77	-71
	no weed control	23	87	90	112	75	-72
Pods	weed-free	--	--	---	---	97	24
	no weed control	--	--	---	---	100	17

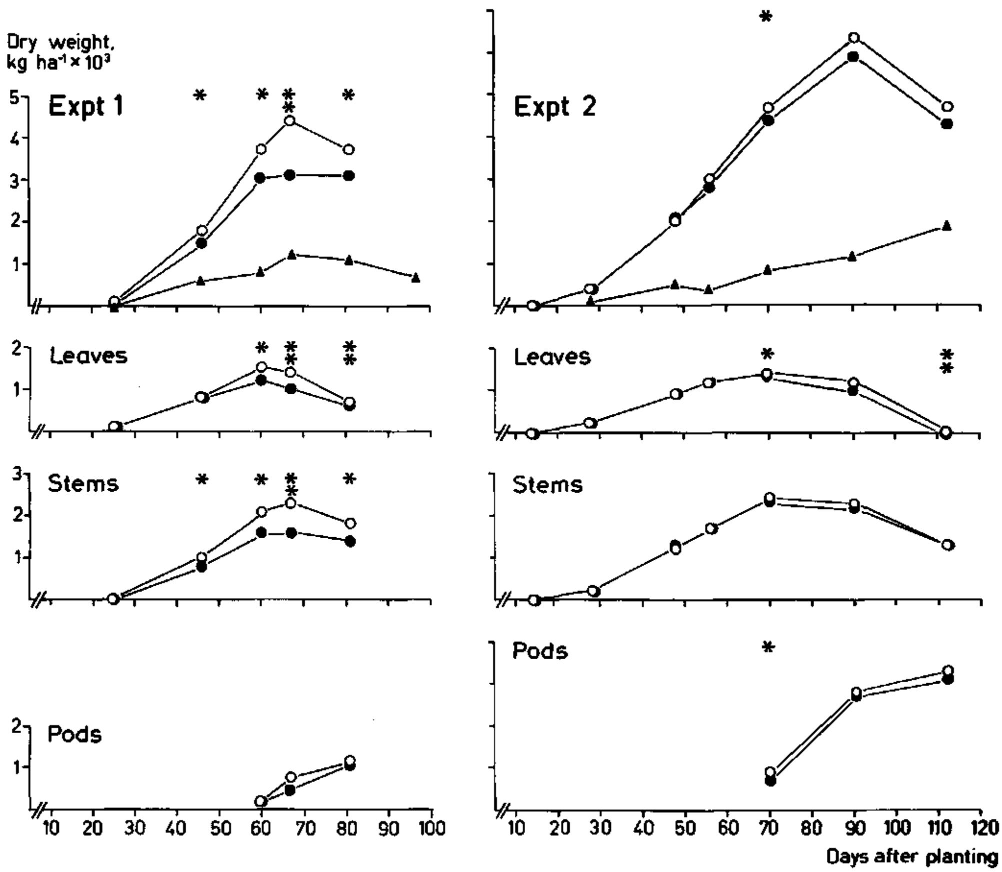

Fig. 4. Dry weight (above-ground parts) of the crop with (o) and without (●) weed control and of the weed vegetation (▲, above-ground parts). Following a one-sided t test a significant difference between treatments is indicated by * (p≤0.05) or ** (p≤0.01).

onwards, severe moisture stress impaired crop growth, in particular in the non-weeded treatments. Pod growth was affected, irrespective of treatment, and possibly partially depended on redistribution of assimilates. Weed weight in Experiment 1 declined from around 70 DAP onwards due to the drought.

In Experiment 2, crop ground-cover and LAI differed only slightly between treatments and differences between growth rate and weight of the crop with and without weed control were small (Table 2, Fig. 4). From 70 DAP onwards, mainly leaf and pod weight were affected. The relative weight of plant parts was not strongly influenced. Weed weight in this experiment increased up to crop harvest.

Development

Plant density was not consistently affected in either experiment (Table 3). Length of the main stem in Experiment 1 was retarded in the crop without weed control at 46 DAP. No differences in stem length were observed before or beyond this date.

The number of nodes in Experiment 1 appeared to have been affected by treatment at 46 DAP only. In contrast with Experiment 1, stem length in Experiment 2 increased with weed competition. The number of nodes in this case was not affected.

In Experiment 1, the number of branches per plant was consistently lower

Table 3. Development of the crop with and without weed control.

		Days after planting						
Expt 1			25	46	60	67	81	97
Number of plants per 3 m^2	weed-free		44	43	43	42	44	46
	no weed control		43	45	48	49	42	40**
Lenght of main stem, cm	weed-free		12.8	47.8	52.7	54.9	48.7	51.5
	no weed control		12.7	42.4*	52.8	53.8	50.2	49.7
Number of nodes on main stem	weed-free		5	11	11	11	11	12
	no weed control		5	10**	11	11	11	11
Expt 2		14	28	48	56	70	90	112
Number of plants per 3 m^2	weed-free	52	59	56	52	57	59	57
	no weed control	57	55*	58	57	57	56	54
Length of main stem, cm	weed-free	8.7	22.6	52.8	56.4	59.5	62.7	57.8
	no weed control	8.9	23.6	54.8	59.0*	63.5	64.8	61.0*
Number of nodes on main stem	weed-free	3	8	12	12	12	11	12
	no weed control	3	8	12	12	12	12	12

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leqslant 0.05$) or by ** ($p \leqslant 0.01$).

Table 4. Development of the crop with and without weed control.

		Days after planting						
Expt 1			25	46	60	67	81	97
Number of branches per plant	weed-free		0.2	4	5	5	6	5
	no weed control		0.1	2*	4	3	4*	4**
Number of inflorescences per plant	weed-free		-	11.2	19.1	16.2	17.1	17.8
	no weed control		-	5.2*	15.1	13.1	15.1	14.6*
Number of pods per plant	weed-free		-	-	33.2	39.7	42.2	46.4
	no weed control		-	-	27.4	28.1	42.6	39.4
Number of pods per inflorescence	weed-free		-	-	1.7	2.4	2.4	2.6
	no weed control		-	-	1.8	2.1	2.8*	2.7
Expt 2		14	28	48	56	70	90	112
Number of branches per plant	weed-free	-	1	3	4	4	3	3
	no weed control	-	1	3	3**	3*	3	2
Number of inflorescences per plant	weed-free	-	-	4.4	15.4	17.7	15.4	15.8
	no weed control	-	-	5.2	11.7*	15.1*	16.2	15.4
Number of pods per plant	weed-free	-	-	-	21.6	46.9	32.1	41.3
	no weed control	-	-	-	14.2*	38.4*	37.0	39.3
Number of pods per inflorescence	weed-free	-	-	-	1.4	2.6	2.2	2.6
	no weed control	-	-	-	1.2	2.5	2.3	2.5*

Following a one-sided t test a significant difference between treatments in indicated by * ($p \leqslant 0.05$) or ** ($p \leqslant 0.01$).

in the non-weeded crop and the same tendency was observed in Experiment 2 (Table 4). The reduction in stem weight observed in Experiment 1 (Fig. 4) must partly be attributed to the reduction in number of branches. In Experiment 2, the much smaller effect on the number of branches was not clearly expressed in stem weight. Reduction in branching due to competition with weeds had also been reported by Fageiry (1987).

The timing of flowering was not influenced by the presence of weeds. The onset of flowering, defined as at least 50 per cent of the plants having produced one flower, was between 39 and 44 DAP in Experiment 1. The percentage of flowering plants was not affected by treatment at 46 DAP. In Experiment 2, the onset of flowering was between 44 and 47 DAP. At 48 DAP no difference in flowering was found between treatments.

In Experiment 1, the number of inflorescences per plant was lower without weed control (Table 4). Because the number of nodes on the main stem was not affected, except at 46 DAP, the lower number of inflorescences is mainly due to the reduction in number of branches per plant. A similar effect was also observed in Experiment 2.

Despite the data being somewhat erratic, in both experiments the number of pods per plant tended to be lower in the treatments without weed control. The data from Experiment 1 would suggest an increase in the number of pods per inflorescence in the non-weeded crop. This effect would partly compensate for the potential reduction in the number of pods per plant due to the lower number of inflorescences per plant. The results from Experiment 2, however, appear to indicate a decrease in the number of pods per inflorescence. Whether competition results in an increase or decrease in the number of pods per inflorescence depends presumably on the timing and degree of competition.

Apart from differences in environmental conditions between seasons and in the composition of weed flora, the limited effects of competition with weeds on growth and development of the crop in Experiment 2 compared with Experiment 1, especially in the early growth stages, can perhaps partly be explained by greater crop competition as a result of the higher plant density in Experiment 2.

It is evident, however, that competition with weeds impairs crop growth, resulting in fewer branches, hence fewer inflorescences and ending in a reduction in the number of pods per plant.

Foliage loss by insects

In Experiment 1 at 25 DAP, it was noticed that crop foliage in both the weeded and non-weeded crop had been damaged by feeding insects, mainly beetles (*Ceratoma variegata* F. and *Diabrotica* cf. *laeta* F.). Later, the non-weeded crop appeared to be the most affected, as confirmed by a visual estimation of damage (1 = heaviest damage, 10 = damage free) at 60 DAP. The weed-free crop scored 6.0, the non-weeded crop scoring 4.1. Insecticide was applied at 69 DAP. At 67 and 81 DAP a comparison of affected leaflets with leaflets with a known affected area, indicated foliage losses of 6 and 11 per cent in the weed-free crop, and 15 and 18 per cent in the non-weeded crop. Whether these foliage losses caused a yield reduction or contributed to differences between treatments cannot be said with certainty. However, the rather limited defoliation seems to make this unlikely. Studies made in South Carolina (Turnipseed, 1972), showed that 17 per cent defoliation at any growth stage did not cause significant yield losses.

Nature of competitive effects

N u t r i e n t s

In Experiment 1, the uptake of N, P and K by the non-weeded crop was considerably lower when compared with the weed-free crop (Table 5)

The significantly lower N concentration at 25 DAP in the crop without weed control (Table 6), and the lower total uptake at that date, indicate that N uptake during the first 25 DAP had been impaired due to the presence of weeds. In the field, this was visible at that time in the slightly pale green colour of the non-weeded crop. However, no significant differences in N concentration were observed after 25 DAP. It is likely, that from then onwards the N-fixing mechanism of the soybean becomes fully operational and that the plants become largely independent of the N supply from the soil. Competition for N thus was only temporary.

The lower K concentrations in the non-weeded crop at 60 and 67 DAP, and the lower total uptake at these dates, indicate competition for K around that time. Part of this effect could possibly be ascribed to the drought around 60 to 67 DAP. Greater moisture stress in the uppermost soil layers in the non-weeded plots may have limited K uptake. In spite of limited rainfall in the period 67 to 81 DAP, K concentration had risen at 81 DAP.

In Experiment 2, apart from one instance for P at 70 DAP, no indications of competition for nutrients were found. Differences in nutrient uptake must largely be ascribed to differences in dry weight between the crops with and without weed control. These results suggest, that despite low soil fertility (Table 1), competition for nutrients between soybeans and weeds is limited. There are several possible explanations for this:

(a) competition for nitrogen, at least in the later stages of crop

Table 5. Nutrient uptake (kg ha^{-1}) of the crop (above-ground parts), with and without weed control, and of the weeds (above-ground parts).

			Days after planting						
Expt 1				25	46	60	67	81	97
N	Crop	weed-free		7	58	102	122	96	-
	Crop	no weed control		6	46	83*	81**	89	-
	Weeds			4	16	17	23	23	15
P	Crop	weed-free		0.6	5.2	9.7	10.9	10.3	-
	Crop	no weed control		0.5	4.3*	8.3	7.8**	9.1**	-
	Weeds			0.3	3.0	3.7	6.7	4.0	2.0
K	Crop	weed-free		6	50	85	86	72	-
	Crop	no weed control		5	42*	59*	44**	63*	-
	Weeds			5	28	35	46	44	36
Expt 2			14	28	48	56	70	90	112
N	Crop	weed-free	3	16	44	62	104	140	139
	Crop	no weed control	3	17	47	64	100	148	154
	Weeds		-	2	16	10	15	21	29
P	Crop	weed-free	0.2	1.4	6.3	9.3	12.7	13.2	14.0
	Crop	no weed control	0.3	1.4	7.1	9.1	11.1**	15.0	15.0
	Weeds		-	0.3	2.3	1.7	2.0	2.7	5.7
K	Crop	weed-free	2	12	57	83	106	113	82
	Crop	no weed control	2	13	60	84	94*	111	83
	Weeds		-	3	27	20	34	44	56

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

growth, does not occur because this is when the plants can fix their own nitrogen;

(b) weed growth was, to a large extent, concentrated between the rows (see *Spatial distribution of weed growth*) and the crop and the weeds may have exploited partly different soil volumes;

(c) the crop had better access to the band-placed fertilizer than the weeds.

Table 6. Nutrient concentration (g kg^{-1}) of the crop (above-ground parts), with and without weed control, and of the weeds (above-ground parts).

			Days after planting					
Expt 1			25	46	60	67	81	97
	Crop weed-free		41.3	32.7	27.4	27.7	26.1	----
N	Crop no weed control		37.2**	30.6	27.2	26.7	28.2	----
	Weeds		28.7	25.7	22.8	18.9	22.9	21.8
	Crop weed-free		3.5	3.0	2.6	2.5	2.8	----
P	Crop no weed control		3.3	2.9	2.7	2.6	2.9	----
	Weeds		4.3	4.5	4.7	5.5	3.7	3.1
	Crop weed-free		36.0	28.7	22.6	19.5	19.6	----
K	Crop no weed control		36.2	27.6	19.5**	14.5**	20.1	----
	Weeds		40.2	44.1	46.1	39.0	42.1	56.5
Expt 2		14	28	48	56	70	90	112
	Crop weed-free	60.5	44.0	22.0	21.1	22.0	22.5	29.5
N	Crop no weed control	58.3	43.9	22.1	22.7	22.8	24.8	35.6
	Weeds	----	39.5	31.5	20.8	19.8	19.9	15.0
	Crop weed-free	5.6	3.8	3.2	3.2	2.7	2.1	3.0
P	Crop no weed control	5.3	3.7	3.3	3.2	2.5*	2.5	3.5
	Weeds	---	4.6	4.4	3.5	3.0	2.7	3.1
	Crop weed-free	38.5	32.4	28.5	28.0	22.5	18.1	17.3
K	Crop no weed control	37.1	33.6	28.3	29.6	21.3	18.8	19.0
	Weeds	----	54.1	52.5	43.3	44.7	37.6	29.2

Following a one-sided t test a significant difference between treatments is indicated by * ($p \leq 0.05$) or ** ($p \leq 0.01$).

L i g h t

In Experiment 1, weeds locally started to overgrow the uppermost crop leaves around 52 DAP and competition for light will have occurred in this experiment.

In Experiment 2, weeds, mainly the inflorescences, had locally overgrown the crop at about 70 DAP. Because of the predominantly gramineous nature of the weed vegetation in this experiment, shading by weeds appeared to be limited. Nevertheless, evidence of competition for light may be deduced from the extra stem elongation in the non-weeded crop (Table 3). Suppression of weed growth by crop shading seems evident from the increase in weed ground-cover with crop leaf-fall towards maturity (Fig. 2).

In view of the comparable height of the soybean canopy and the local weeds, competition for light between soybeans and weeds is likely to be a common phenomenon.

W a t e r

In Experiment 1, severe moisture stress is expressed in the decline of weed ground-cover, as observed at 60 DAP and, irrespective of treatment, in the rapid decline in ground-cover and LAI of the crop after 60 DAP, due to withering and leaf-fall. In the non-weeded crop, in particular after 60 DAP, competition for water by the weeds will have added to crop moisture stress, resulting in the reduced growth rates shown in Table 2.

Neglecting the potentially rather limited (Boxman et al., 1985) amount of soil-available water, in Experiment 2 potential evapotranspiration of a weed-free crop considerably exceeded available moisture by rainfall from about 35 to 65 DAP (Fig. 1). In view of the probably higher evapotranspiration of the non-weeded crop and weeds combined, because of the higher ground-cover of this combination, competition for water between the crop without weed control and weeds in this period seems to be evident. Moisture stress is likely to have caused the decline in weed ground-cover in the period 56 to 70 DAP, while probably further contributing to the differences in ground-cover, LAI and weight at 70 DAP (Figs. 2, 3 and 4) between the crop with and without weed control.

C o n c l u s i o n

Competition between soybeans and weeds under local conditions, using current cultivation methods, will mainly be for light and water, the latter depending on rainfall. Competition for nutrients may occur but is likely to be of only limited importance. Comparable results were found in Zimbabwe. With adequate rainfall, competition between soybeans and weeds was mainly for light (Thomas and van Lindert, 1980). Fageiry (1987) reported that low yields due to competition with weeds, were associated with reduced leaf N concentration at flowering, indicating impaired N uptake. No fertilizers were applied in his experiment, however, and this may have aggravated competition for N, especially in the early crop growth stages.

Weed-free period after planting

Yields (Table 7) in Experiment 1 were low due to the drought which caused accelerated, uneven ripening. In both experiments, yields were not significantly influenced by the length of the weed-free periods, although lowest yields were obtained under the shortest weed-free periods. With 25 weed-free DAP in Experiment 1, measurable amounts of weed growth were observed in only one plot at harvest (197 kg ha^{-1}). No measurable amounts of weeds

Table 7. Yield (12% moisture) and yield components with increasing periods with and without weed control.

		Period, days after planting						
Expt 1			0–25	0–46	0–60	0–67	0–81	0–96
Yield,	weed-free		620 abc	799 a	765 a	707 ab	654 ab	751 a
kg ha^{-1}	no weed control		610 abc	673 ab	709 ab	651 ab	404 c	482 bc
Number of	weed-free		39 a	39 a	40 a	41 abc	40 a	46 c
plants per 3 m^2	no weed control		42 abc	41 ab	43 abc	42 abc	40 a	45 bc
1000–seed	weed-free		100 ab	101 ab	98 abc	101 ab	105 ab	102 ab
weight, g	no weed control		99 abc	106 ab	102 ab	110 a	94 bc	88 c
Expt 2		0–14	0–28	0–48	0–56	0–70	0–90	0–113
Yield,	weed-free	2450 abc	2681 ab	2536 ab	2540 ab	2728 a	2687 ab	2584 ab
kg ha^{-1}	no weed control	2719 a	2578 ab	2635 ab	2695 ab	2428 abc	2395 bc	2239 c
					n.s.			
Number of	weed-free	51	58	58	49	55	58	57
plants per 3 m^2	no weed control	54	53	56	53	54	56	52
1000–seed	weed-free	204 abc	196 abd	203 abc	197 abd	210 abc	210 abc	199 ab
weight, g	no weed control	201 ab	194 bd	201 ab	217 c	211 ac	196 abd	183 d

For each variable, figures followed by the same letter are not significantly different ($p \leqslant 0.05$) according to Duncan's New Multiple Range Test. (n.s. = non-significant).

were found at harvest in the other treatments. Weed growth was, however, affected by the drought.

In Experiment 2, with 14 weed-free DAP, 500 kg ha^{-1} of weeds were found at harvest. Apart from possible competitive effects, such an amount of weed growth at harvest could possibly obstruct combine-harvesting or affect seed quality. Only 13 and 27 kg ha^{-1} of weeds were present at harvest with 28 and 48 weed-free DAP, respectively, and no measurable amounts with longer weed-free periods.

No effects of the length of the weed-free periods on plant density or on 1000-seed weight were observed.

These data suggest that the soybean crop should be kept weed-free for about four weeks after planting to avoid yield losses or too much weed growth at harvest.

Period after planting without weed control

In both experiments, yields decreased with increasing periods without weed control (Table 7). Yield reduction was observed after a period of no weed control of 81 DAP in Experiment 1 and of 70 DAP in Experiment 2. These periods are long when compared with data in the literature. Hammerton (1972) reported that three weeks of weed competition after emergence reduced soybean yields. Sistachs and Leon (1975) found yield reduction with competition up to 30 days after planting. On average of four seasons Thomas and van Lindert (1980) observed reduced yields with competition up to four weeks after planting. In the present experiments, competitive effects of the weeds on yield thus appear to be comparatively small.

The lower yield in Experiment 1 with 81 DAP without weed control, compared with no weed control at all, can probably be partly attributed to the inevitable disturbance of the crop, under the prevailing dry conditions, during weed removal.

In neither experiment was plant density consistently affected. Density can, however, sometimes be substantially reduced. Thomas and van Lindert (1980) found a reduction in some cases of more than 75 per cent in plant density due to the presence of weeds.

Only when the crop was without any weed control at all was the 1000-seed weight influenced to any considerable degree. In Experiment 2, seeds of this treatment appeared small and irregular, and often attacked by fungi, while this treatment contained more germinated seeds than the other treatments. Seed quality was not evaluated in Experiment 1.

In view of the absence of effects on plant density, the yield reductions must be ascribed to the reduction in the number of pods (Table 4) and weight per seed (Table 7). As to how far a reduced number of seeds per pod could have contributed to the lower yields was not investigated. In the literature negative effects and absence of effects of crop-weed competition on number of seeds per pod are both reported (Watanabe et al., 1981; Durigan et al., 1983; Dubey et al., 1984; Harris and Ritter, 1987). Moisture stress did not appear to influence number of seeds per pod (Villalobos-Rodriguez and Shibles, 1985).

Although weed growth adversily affects early growth (Fig. 4) and development (Tables 3, 4) of soybeans, it does not reduce yields when weeds are subsequently removed, i.e. after 60 - 67 DAP in Experiment 1 and 56 DAP in Experiment 2. Up to those periods yield potential apparently was not affected. However, when weed growth is allowed to continue beyond these periods, when the number of pods had been established (Table 4), yield potential was irreversibly affected, and the plants could no longer compensate. With competition up to 67 DAP (Expt 1) and 56 DAP (Expt 2), when the number of inflorescences had completely or almost completely been established, the crop may have compensated for the lower number of inflorescences per plant by increasing the number of pods per inflorescence. The high 1000-seed weights with competition up to both dates (Table 7) suggest that the crop, at least to some extent, compensated by increasing weight per seed.

These data indicate that absence of competition in the period of pod initiation, i.e. the period around 45 to 70 DAP (Table 4), is critical to avoid yield reductions. The length of the period generally required after planting, during which time the crop should be weeded, four to about six (seven) weeks, seems to support this observation. Also, the length of the required period for weed control under temperate conditions, around three (Harris and Ritter, 1987) to four (five) weeks after planting (Burnside, 1979; Horn and Burnside, 1985), may imply avoidance of competition during pod initiation. Based mainly on data from temperate areas, van Heemst (1985) estimated the critical period for crop-weed competition in soybean as from 0.12 up to 0.30 of the total crop growth period.

In view of the effects of the drought in Experiment 1, which may have influenced the results, and the limited effects of competition in Experiment 2, continued evaluation of competition between soybeans and weeds along the present lines is recommended. In order to gain more insight into the effects of competition with weeds on crop development, the number of inflorescences and pods per plant should preferably also be established at harvest in all treatments.

Spatial distribution of weed growth

In Experiment 2, weed growth at harvest appeared to be largely concentrated between the crop rows (Fig. 5). The band-placement of the fertilizers ensured that the crop had good access to the nutrients applied, while limiting access to the weeds (Chapter VII). This, combined with rapid establishment of some ground-cover by seedlings, because of large seed size, gave the crop a competitive advantage over the weeds. The more rapid canopy closure in the rows than between them limited weed growth in the row. Under the same conditions, a similar distribution of weed growth was found in groundnuts (Chapter III). With sorghum, however, more weed growth was found in the rows than between them, mainly due to a more open canopy structure (Chapter IV).

Practical implications

It may be concluded that the soybean crop should be kept weed-free up to about four weeks after planting. The data on spatial distribution of weed growth emphasize the need for weed control between the rows. To reduce dependence on chemical weed control, it is considered necessary to investigate whether two mechanical weedings, as wide as possible between the rows, at about three to four weeks after planting, would be sufficient to avoid

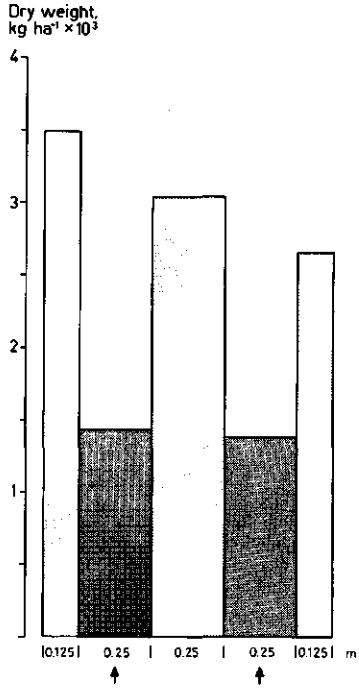

Fig. 5. Spatial distribution of uncontrolled weed growth at harvest (Expt. 2; crop rows indicated by arrows).

yield losses and the presence of too much weed growth at harvest. Decreasing row width while maintaining plant population could further add to crop competitiveness (Hammerton, 1972; Nangju, 1980).

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Chapter VI

RESPONSE OF WEEDS TO FERTILIZER APPLICATION
I. EFFECTS OF NITROGEN, PHOSPHORUS AND POTASSIUM

Introduction

Studies on the competition between crops and weeds in Suriname have shown that inadequate weed control can lead to considerable yield losses in groundnuts, sorghum and soybeans (Chapters III, IV and V). Competition in groundnuts and soybeans concentrated on water and light. With sorghum, light was not considered to have played an important role, but apart from competition for water, there was strong and early competition for nutrients.

These studies were made on low fertility acid soils of the Zanderij area in Suriname. Natural nutrient content in these soils is critically low (Schroo, 1976), and sustained fertilizer use is essential if acceptable yield levels are to be obtained (Boxman et al., 1985).

Fertilizer application can influence both the competitive relationships between weeds and crops (Alkämper, 1976; Moody, 1981) and the composition of the weed flora. The latter with long term application (Eden and Bond, 1945; Jahn-Deesbach and Vogt, 1960; Hengst, 1981), as well as in the same season of application (Freyman, Kowalenko and Hall, 1989).

To complement the studies on competition, attention was therefore also paid to the effect of fertilizer application on weed growth. The first part of this paper reports the effects of nitrogen, phosphorus and potassium. The second part (Chapter VII) describes the effects of the method of fertilizer application.

Materials and methods

General

The experiments were done at the experimental farm Coebiti (see Chapter I) during the short rainy season of 1983-84 on a loamy sand and a sandy loam soil. The soils belong to the yellow kaolinitic Oxisols intergrading towards Ultisols (Bennema, 1982) and are acid and of low fertility. The study done on the sandy loam was started twenty days later than the one on the loamy sand.

Experimental procedures

The experiments were of a 2^3 factorial design, replicated six times. Nitrogen, P and K were applied at the rates of 50, 50 and 40 kg ha^{-1}, in the form of urea, triplesuperphosphate and potassium magnesium sulphate (at the applied rate, the last fertilizer included 10 kg ha^{-1} Mg). To compare different NPK formulations, an application of N, P and K at rates of 50, 50 and 40 kg ha^{-1}, in the form of compound NPK (15:15:15) and triplesuperphosphate was included in the experiments, treatment *NPK*. The rates of application apply to the range of recommendations for crops at planting (total N and K applications to crops are two to three times as high). The fertilizers were broadcast after soil preparation which consisted of disc-harrowing, ploughing and harrowing, and were lightly worked in by hand. No crop was planted. Insecticides were applied for control of noxious insects.

The plot size was 1 x 1 m. Net plots measured 0.75 x 0.75 m. The above-ground part of the naturally developed weed vegetation was harvested at 49 days after fertilizer application at the loamy sand location, and at 35 days at the sandy loam location. The weeds were oven-dried at 85 ^{o}C (24 h) and 105 ^{o}C (2 h). The uptake of N, P and K of the combined weeds from each plot of two replicates at the sandy loam location was determined. These weeds were oven-dried at 70 ^{o}C (24 h). The degree of ground-cover of the weed vegetations was visually estimated by two observers at intervals of about a week. On the loamy sand, at 21 and 35/36 days, the number of plants were counted in one of the nine 0.25 x 0.25 m divisions of each plot. Similar counts were made at 22 to 24 days in three replicates on the sandy loam.

Soil fertility

Composite soil samples of each replicate were taken before soil preparation and analysed for their chemical properties. Soil fertility and pH at the loamy sand location were considerably lower than at the sandy loam location (Table 1). Due to liming and fertilizer application under previous

Table 1. Chemical properties of the soil (0-20 cm) of the experimental fields.

Location	Loamy sand	Sandy loam
Org. C, g kg^{-1}	10.0	13.3
Org. N, g kg^{-1}	0.8	1.2
pH-KCl	4.1	4.7
pH-H_2O	4.8	5.6
Exch. Ca, mmol(+) kg^{-1}	2.8	11.8
Mg, mmol(+) kg^{-1}	0.4	3.0
K, mmol(+) kg^{-1}	0.5	1.4
Na, mmol(+) kg^{-1}	0.2	0.6
Al, mmol(+) kg^{-1}	11.0	4.3
ECEC, mmol(+) kg^{-1}	14.9	21.0
100 x exch. Al/ECEC	74	20
CEC, pH7, mmol(+) kg^{-1}	36.8	47.8
P-Bray I, mg kg^{-1} P	12.2	33.6

(ECEC = Effective Cation Exchange Capacity; CEC = Cation Exchange Capacity).

cultivation, soil fertility (especially P) and pH had improved compared with natural conditions. Under natural conditions, pH-KCl and pH-H_2O of sandy loams are in the region of 3.7 and 4.2 respectively, and P-Bray I about 2 mg kg^{-1} (Boxman et al., 1985), while soil fertility indices of loamy sands may be lower.

Results and discussion

Weed species

Primary species at the loamy sand location were *Borreria latifolia* (Aubl.)

Schum., *Brachiaria decumbens* Stapf, *Croton hirtus* L'Hérit., *Croton trinitatis* Millsp., *Digitaria horizontalis* Willd., *Paspalum melanospermum* Desv. ex Poir., *Phyllanthus stipulatus* (Rafin.) Webster, *Mollugo verticillata* L., and *Sebastiania corniculata* (Vahl) Müll.Arg.. At the sandy loam location *Eleusine indica* (L.) Gaertn. dominated the weed vegetation.

Ground-cover

The experiment at the loamy sand location suffered from damage by insects, while heavy showers resulted in surface run-off affecting fertilizer distribution and seedling establishment.

Ground-cover of the weed vegetation at the loamy sand location developed only slowly (Table 2.) At 21 days, ground-cover of some plots was still less than five per cent and was not recorded. Ground-cover at the sandy loam developed more rapidly than at the loamy sand. At the latter location significant effects of N, P and K on ground-cover were found at four weeks. The effects of P and K disappeared with time and only the N effect remained. At the sandy loam location, there were significant effects of N and P. At 24 days, N and P interacted positively. At 30 days, without N, the P effect was absent in the presence of K. Potassium had no effect on ground-cover development at this location. Changing the NPK formulation had no effect on either location.

Table 2. Ground-cover (%) of the weed vegetation as influenced by fertilizer application.

Location	Fertilizer treatments -N	+N	-P	+P	-K	+K	Significant effects		
Loamy sand									
28 days	11	24	14	21	15	21	N($p<0.001$)	P($p=0.027$)	K($p=0.038$)
35 days	25	41	30	36	30	35	N($p<0.001$)	P($p=0.035$)	K($p=0.049$)
44 days	40	59	46	52	45	53	N($p<0.001$)		K($p=0.011$)
48 days	50	68	58	61	57	62	N($p<0.001$)		
Sandy loam									
24 days	33	65	40	58	48	50	N($p<0.001$)	P($p<0.001$)	N*P($p=0.028$)
30 days	48	75	55	68	61	62	N($p<0.001$)	P($p<0.001$)	N*P*K($p=0.047$)

Number of plants

The application of nutrients did not affect the number of cyperaceous weeds at the loamy sand location (Table 3). Potassium was found to have a positive

Table 3. Number of plants (0.0625 m^{-2}) of the weed vegetation as influenced by fertilizer application.

Location, species	-N	+N	-P	+P	-K	+K	Significant effects	
Loamy sand								
21 days								
Broadleaved spp.	14	14	12	16	11	17	K(p=0.006)	
Gramineae	11	16	12	15	12	15	K(p=0.027)	
Cyperaceae	3	5	4	4	3	5		
Total	28	34	28	34	26	37	K(p=0.005)	
35 days								
Broadleaved spp.	17	18	17	18	15	20	K(p=0.044)	
Gramineae	12	17	14	15	13	16	N(p=0.007)	
Cyperaceae	5	6	6	5	5	6		
Total	34	40	36	38	33	41	K(p=0.032)	
Sandy loam								
23 days								
Eleusine indica	100	99	99	100	87	112	K(p=0.002)	P*K(p=0.014)
Others	20	18	21	17	18	20		
Total	120	117	120	117	105	132	K(p=0.006)	P*K(p=0.018)

effect on the number of broadleaved weeds and on the total number of plants, while N increased the number of grasses. A positive effect of K on plant numbers was also found at the sandy loam location for both *Eleusine indica* and the total number of plants. Potassium interacted significantly with P in this case - the effect of K was expressed most strongly in the absence of P. The relatively small numbers of plants, other than for *E. indica*, was not influenced by treatment. Difference in NPK formulation had no effect on the number of plants at either location.

These results show that the floristic composition of the weed floras, in terms of plant numbers, was influenced by fertilizer application.

At the loamy sand location the positive effect of both K and N on plant numbers is likely to have contributed to the increase in ground-cover with application of these nutrients (Table 2). The increased number of plants with an application of K did not influence the ground-cover at the sandy loam location. Because of the high plant density at this location, the increase in the number of plants possibly resulted in smaller plants.

In contrast to the positive effect of N on the number of grasses at the loamy sand location, no such effect was found for the grass *Eleusine indica* at the sandy loam location.

Positive effects of N on grass germination and seedling emergence have been mentioned in the literature. Dale (1975) reported positive effects of potassium nitrate on germination of *Eleusine indica* under laboratory conditions and on seedling emergence in soil samples in the greenhouse. Agenbag and de Villiers (1989), and Freyman et al. (1989), described positive effects of ammonium nitrate fertilizers on seedling emergence of *Avena fatua L.* and unnamed grasses respectively, in greenhouse observations.

No effect of P on plant numbers, except for the interaction with K at the sandy loam, was observed. Freyman et al. (1989) found stimulatory effects of early spring field applied P on numbers of *Spergula arvensis* L. and *Capsella bursa-pastoris* L.. Late spring application, however, showed no effect.

It cannot be stated with certainty whether the positive effect of N and K on plant numbers is an effect on the germination of seeds or on the establishment and survival of seedlings, or a combination of both. Under laboratory conditions, the germination of many weed species is promoted by N, particularly nitrate (Steinbauer and Grigsby, 1957). Field response to N fertilizer, however, is likely to be influenced by environmental factors, such as soil moisture, soil temperature and N mineralization, type of N fertilizer and timing of application (Freyman et al., 1989), rate of application (Hurtt and Taylorson, 1986; Freyman et al., 1989), and laboratory results cannot be directly transferred to field conditions (Fawcett and Slife, 1978).

No effects of K on germination have been found in the literature, but as K may increase the strength of plants and may raise resistance to disease (Mengel and Kirkby, 1978), it is suggested that K, especially if abundantly available in the uppermost centimetres of the soil, improved the establishment and survival of the seedlings.

Dry matter yield of weeds

At the loamy sand location, a significant response in dry weight was only produced by N (Table 4, Fig. 1). Significant effects at the sandy loam location were found with N and P. Here N and P interacted positively. Application

Table 4. Dry matter yield of weeds (kg ha^{-1}) as influenced by fertilizer application.

Location	Fertilizer treatments -N	+N	-P	+P	-K	+K	Significant effects		
Loamy sand	503	1244	818	930	795	953	N($p<0.001$)		
Sandy loam	818	2183	1223	1778	1454	1548	N($p<0.001$)	P($p<0.001$)	N*P($p=0.006$)

of K had no effect at either location. Apparently, at both locations, the soil-available K was adequate for growth at the time. NPK gave a significantly ($p\leq0.05$) higher response than the *NPK* compound fertilizer at the loamy sand location, but no significant difference was found at the sandy loam. In view of the limited amount of Mg available in the soil at the loamy sand location (Table 1), the higher response to NPK may very likely be attributed to the presence of Mg in the formulation NPK.

The effects that the different nutrients had on the dry weight, agree with the effects on ground-cover of the weed vegetation (Table 2).

At neither location was the positive effect of K on the number of plants (Table 3) ultimately reflected in the dry weight. The positive effect of N on the number of grasses at the loamy sand location, however, may have contributed to the increase in dry weight with the application of N.

Difference in dry matter yield between the two locations

Despite the earlier harvesting date, the overall weight of weeds at the sandy loam location was considerably higher than at the loamy sand location (Fig. 1). Although the experiments were not started concurrently, rainfall

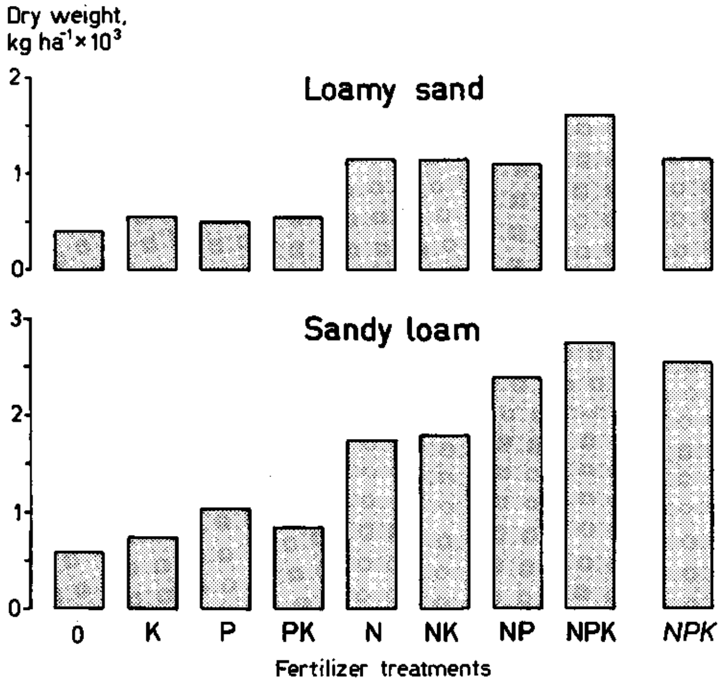

Fig. 1. Dry matter yield of weeds as influenced by fertilizer application.

(Fig. 2) and radiation - a daily average of 1701 J cm^{-2} at the loamy sand against 1715 J cm^{-2} at the sandy loam - are not likely to have induced substantial differences in weight of weed growth between the two locations. As there was no response in weight to applied P and K, the lower soil fertility of the loamy sand (Table 1) is also not likely to have been responsible for this difference.

Damage by leaf-eating insects and heavy rainfall, resulting in surface run-off, transport of fertilizer and damage to seedlings, has been observed at the loamy sand site. The importance of these negative effects cannot be quantified.

Despite this uncertainty it is thought that the difference in weed weight, at least partly, was caused by the difference in weed species composition between the two locations.

On the experimental farm most of the species of the loamy sand location -

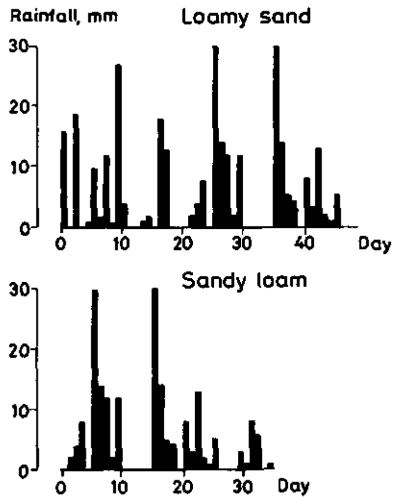

Fig. 2. Daily rainfall during the experiments.

apart from *Brachiaria decumbens* which occurred in the field as a relic of cultivation at Coebiti - are usually more commonly found on locations of comparatively low fertility and generally exhibit low growth rates. They apparently are adapted to low fertility conditions and therefore grow slowly and are less responsive to fertilization (Chapin, 1980). In contrast to this, species with a preference for more fertile conditions, such as *Eleusine indica*, usually have high growth rates and respond well to fertilizer application (Chapin, 1980).

Uptake of nutrients at the sandy loam location

The application of N and P increased the uptake of N, P and K (Table 5). The high apparent recovery rate for N fertilizer suggests that despite regular rainfall (Fig. 2) and the permeability of these soils (Schroo, 1976), little leaching of N beyond the rooting zone took place.

The quantity of K taken up without application of this nutrient indicates the presence of considerable amounts of soil-available K and explains the absence of a response in weight to application. Changing the NPK formulation

Table 5. Nutrient uptake (kg ha^{-1}) of N, P and K by the weed vegetation at the sandy loam as influenced by fertilizer application.

Nutrient taken up	Fertilizer treatments -N	+N	-P	+P	-K	+K	Apparent fertilizer recovery, %
N	25.0	64.0	39.2	49.9	44.6	44.5	78
P	3.3	8.5	5.2	6.6	5.8	6.1	3
K	32.2	93.7	53.1	72.8	60.9	64.9	10

caused no substantial differences in nutrient uptake. Uptake of nutrients without fertilizer application was 18.0 kg N, 2.4 kg P and 21.9 kg K per hectare. For the NPK application these figures were 72.1 kg N, 10.1 kg P and 120.9 kg K respectively. The latter amounts of nutrients, taken up in only 35 days, illustrate the potential for competition for nutrients with crops.

Conclusion

Nitrogen application stimulated both the growth of a weed vegetation, more commonly found on locations of low fertility, and of a vegetation dominated by *Eleusine indica*, usually found on locations of comparatively high fertility. Phosphorus only stimulated growth of the latter vegetation. The application of K gave no response in weight, but increased the number of plants at both locations. Thus, weeds responded to fertilizer application, but response varied with the weed vegetation and the kind of nutrient applied.

Practical implications

In view of the response to fertilizer application, the practical implications of the present data are that adequate weed control is especially important when *Eleusine indica* forms an important part of the weed vegetation.

In general at the experimental farm, there are indications that with regular cultivation, including liming and fertilizer application - causing repeated soil disturbance, reduced soil acidity, and build up of soil-available P - the weed vegetation at the experimental farm may change from a mixed vegetation to one where *Eleusine indica* forms an important part or dominates. With such a shift in weed flora the importance of weed control increases.

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Chapter VII

RESPONSE OF WEEDS TO FERTILIZER APPLICATION
II. EFFECTS OF THE METHOD OF FERTILIZER APPLICATION

Introduction

In Part I (Chapter VI) the effects of different nutrients on the growth of weeds on low fertility acid soils in Suriname were described. Part II deals with the effects of the method of fertilizer application.

It was observed in the field, that where crop growth failed, weed growth tended to be concentrated in the plant rows. It was thought that this was mainly attributable to the band-placing of fertilizers close to the crop rows. Without a crop, weed growth on these low fertility soils would be concentrated on the fertilized bands.

In order to test this hypothesis, experiments were set up to compare the effects of band-placing and broadcasting of fertilizers on the growth of weeds. As fertilizers were band-placed with a planting machine equipped with planter press wheels, the possible effect of soil compaction by the planter press wheels on weed growth was also investigated.

The results of the experiments are discussed in relation to the spatial distribution of weed growth found in groundnuts, sorghum and soybeans (Chapters III, IV and V).

Materials and methods

General

For details concerning location, climate and soils, see Part I of this paper (Chapter VI). The experiments were done during the short rainy season of 1983-84 on a loamy sand and on a sandy loam soil. The experiment done on the sandy loam was started twenty days later than the one on the loamy sand.

Experimental procedures

The treatments, applied after soil preparation, which consisted of disc-harrowing, ploughing and harrowing, were as follows:

- I fertilizers applied with a planting machine, at rates of 48 kg N, 48 kg P and 40 kg K ha^{-1}, in a narrow band several centimetres deep, in the planter press wheel furrows;
- II no fertilizers applied; planter press wheel furrows drawn with a planting machine;
- III fertilizers applied broadcast at the same rates as under I, lightly raked in; no planter press wheel furrows;
- IV no fertilizers applied, soil surface lightly raked; no planter press wheel furrows.

The planting machine used was a tractor-mounted pneumatic precision planter, equipped with double-disc openers for fertilizer application, and runner openers for sowing. The runner openers were placed behind the double-disc openers, in front of a pair of press wheels. Four furrows, 0.5 m apart, were drawn simultaneously within a 2 m working width. Plot width equalled working width, and plot length was 3.5 m. The fertilizers were applied in the form of NPK (15:15:15) and triplesuperphosphate. No crop was planted. Insecticides were applied for control of noxious insects.

The above-ground part of the weed vegetation in the centre 2 x 1 m of each plot was harvested in five adjoining strips 0.125, 0.25, 0.25, 0.25 and 0.125 m wide, lengthwise over the plot (Fig. 1). The weeds were harvested at 49 and 50 days after the start of the experiment at the loamy sand location, and at 43 and 44 days at the sandy loam location. The weeds were oven-dried at 85 °C (24 h) and 105 °C (2 h). The experiment had six replicates and was analysed as a split-plot design.

Soil fertility

Composite soil samples of each replicate were taken before soil preparation and analysed for their chemical properties. The data are presented in Table 1.

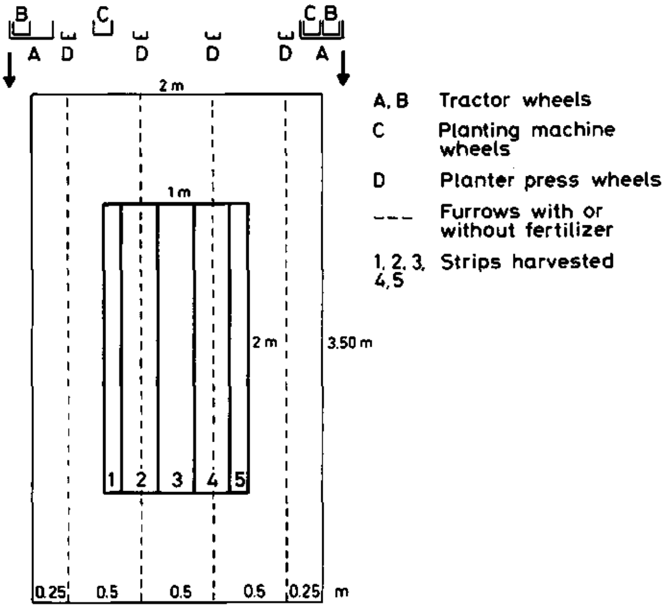

Fig. 1. Lay-out of an experimental plot.

Compared with the natural fertility of these soils (Schroo, 1976; Boxman et al., 1985) pH and fertility at both sites had already been improved under previous cultivation. Soil fertility indices of the loamy sand location were still considerably lower than those of the sandy loam location.

The difference in composition of the weed flora at both locations probably reflected these conditions (see Part I, Chapter VI).

Results and discussion

Weed species

Primary species at the loamy sand location were, *Borreria latifolia* (Aubl.) Schum., *Brachiaria decumbens* Stapf, *Croton hirtus* L'Hérit., *Digitaria hori-*

Table 1. Chemical properties of the soil (0-20 cm) of the experimental fields.

Location	Loamy sand	Sandy loam
Org. C, g kg^{-1}	11.0	11.9
Org. N, g kg^{-1}	0.8	1.1
pH-KCl	4.2	4.8
pH-H_2O	5.0	5.8
Exch. Ca, mmol(+) kg^{-1}	4.3	13.5
Mg, mmol(+) kg^{-1}	1.2	4.2
K , mmol(+) kg^{-1}	0.6	2.0
Na, mmol(+) kg^{-1}	0.5	0.4
Al, mmol(+) kg^{-1}	10.0	3.0
ECEC, mmol(+) kg^{-1}	16.5	22.9
100 x exch. Al/ECEC	60	13
CEC, pH7, mmol(+) kg^{-1}	32.9	44.6
P-Bray I, mg kg^{-1} P	18.7	40.8

(ECEC = Effective Cation Exchange Capacity; CEC = Cation Exchange Capacity).

zontalis Willd., *Paspalum melanospermum* Desv. ex Poir., *Phyllanthus stipulatus* (Rafin.) Webster, *Mollugo verticillata* L. and *Sebastiania corniculata* (Vahl) Müll.Arg.. The weed vegetation at the sandy loam location was dominated by *Eleusine indica* (L.) Gaertn.

Dry matter yield of weeds

Data on weed growth under the different treatments are presented in Table 2. Weed growth at the loamy sand location was smaller than that at the sandy loam location

Fertilizers increased weed growth at both locations, but response to fertilizers band-placed in furrows was smaller than to fertilizers broadcast. This effect is ascribed to the limited availability of nutrients to the weeds if the fertilizer is placed in a narrow band several centimetres deep. Reduction in weed growth was relatively greater at the loamy sand location than at the sandy loam location.

The experiment at the loamy sand suffered from damage by insects, and as a result of the sometimes heavy rainfall and the slight sloping of the

Table 2. Effect of the method of fertilizer application on the amount of weeds (dry weight, kg ha^{-1}).

Location	Fertilizer band-placed in furrows Furrows	No fertilizer Furrows	Fertilizer broadcast No furrows	No fertilizer No furrows
Loamy sand	733 b	444 c	1721 a	497 c
Sandy loam	2661 b	1962 c	4212 a	1982 c

For each location, figures followed by the same letter are not significantly different ($p \leqslant 0.05$) according to Duncan's New Multiple Range Test.

field, surface erosion occurred at this location. This erosion will have affected seedling establishment in general. It certainly affected the fertilizer broadcast treatment as fertilizer granules were found outside the plots. Weed growth with this treatment could therefore possibly have been higher than was actually measured.

The presence of planter press wheel furrows - without fertilizer application - did not apparently influence the weight of weeds (Table 2). The light raking of the soil surface in the no fertilizer, no furrows treatment is not expected to have significantly influenced weed establishment.

Spatial distribution of weed growth

The spatial distribution of weed growth in the different treatments is shown in Fig. 2. In the treatments on the loamy sand no significant differences ($p \leq 0.05$) were found between weed growth on the different strips. Weed growth on the respective strips of treatment II did not differ significantly from those in treatment IV. For the no fertilizer, furrows treatment, it means that soil compaction by the planter press wheels did not influence weed growth, confirming the observation made above.

With the fertilizers band-placed in the furrows (Treatment I) weed growth on the strips where the fertilizer was placed was higher than on the adjacent strips. The increase in weed growth with this treatment (Table 2) thus appeared to be concentrated on the fertilized bands.

At the sandy loam soil, weed growth in treatment IV did not differ significantly between strips. In treatment II weed growth on strips 2, 3, 4 and

5 did not differ between these strips, nor from the corresponding strips in treatment IV. This again shows the absence of an effect of planter press wheels. Strip 1 of treatment II is discussed below.

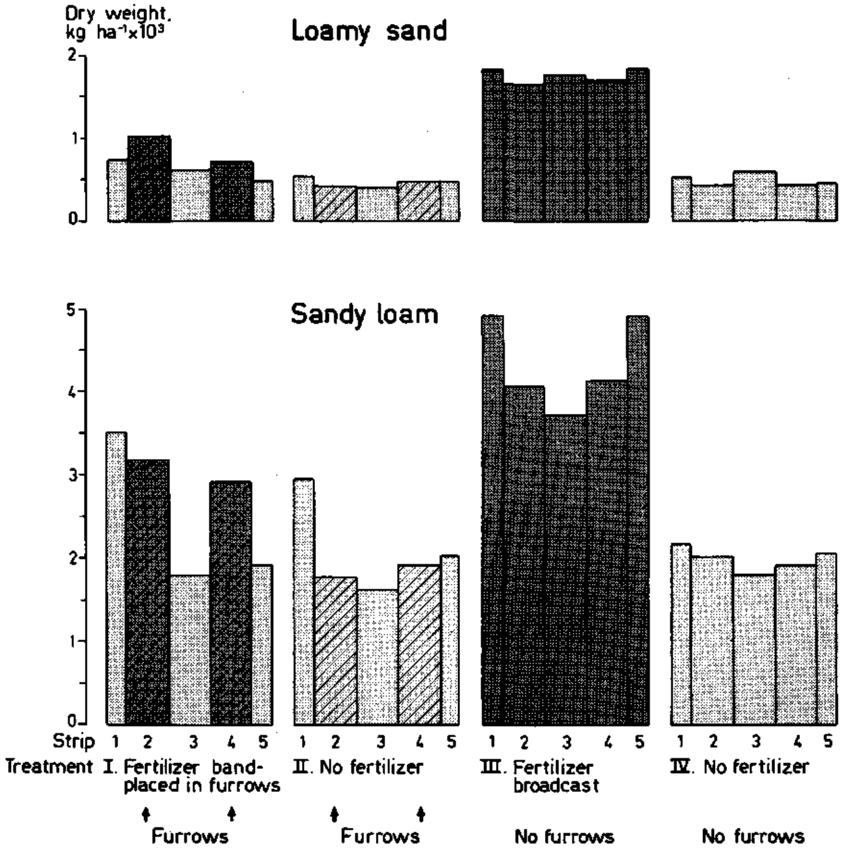

Fig. 2. Spatial distribution of weed growth as influenced by the method of fertilizer application.

With the fertilizer broadcast, without furrows, weed growth on strips 1 and 5 was equal and significantly more than on strips 2, 3 and 4. At this location no surface erosion was noted, except for some soil washing with the first rains after the start of the experiment. The symmetry in the distribution of weed growth could suggest, however, that fertilizer, either as granules or dissolved, may have been carried sideways with excess run-off water towards the tractor wheel tracks at the long sides of the plots. It could perhaps also be speculated, whether with little or no fertilizer transport, in this case, with vigorous weed growth, weeds towards the long sides of the plots found more favourable soil water conditions due to collection of run-off water in the tractor wheel tracks. No data are available, however, to substantiate these ideas.

With the fertilizers band-placed in the furrows (Treatment I) weed growth on strips 2 and 4 was significantly more than on strips 3 and 5, while no difference in weed growth on strips 3 and 5 was observed between this treatment and the no fertilizer treatments. Thus, weed growth was concentrated on the fertilized bands. Strip 1 of this treatment is discussed below.

It is concluded, therefore, that band-placing of fertilizers in the planter press wheel furrows compared with broadcasting, reduced weed growth (Table 2), and the weed growth that was present was concentrated on the fertilized bands (Fig. 2). The low fertility of the soils (Table 1) will have accentuated this effect. Weed establishment and growth at both locations were clearly earlier and stronger with fertilizers broadcast than with band-placement. No symptoms of salt damage - possibly caused by the concentrated band-placement of fertilizers - were observed. Adequate rainfall during the experiments probably precluded such an effect.

At the sandy loam, weed growth in treatment I on strip 1 significantly exceeded that on strips 3 and 5 and did not differ from that on strips 2 and 4. In treatment II at this location, weed growth on strip 1 was significantly higher than on the other four strips and not significantly different from strip 1 in treatment I.

The effect can be ascribed to the whole, or part of, a wheel of the planting machine running in strip 1 (see Fig. 1). By soil compaction, probably resulting in improved seed-soil water contact and capillary conductivity, weed growth in the planting machine wheel track was apparently stimulated. Likely because of different soil conditions this effect was not obvious on the loamy sand.

The effect of soil compaction on weed growth, whether positive (Roberts and Hewson, 1971) or possibly negative - e.g. through increased resistance to seedling emergence - will, among other factors, depend on the degree to which the soil structure is modified by the pressure exerted and on soil moisture conditions. Under the prevailing conditions, the force of the planter press wheels was apparently not sufficient to create an effect, while the pressure of the planting machine wheel created a positive effect. It would appear therefore, that, depending on the conditions, soil compaction can have an effect on the spatial distribution of weed growth.

As the experimental design does not include the treatments band-placement of fertilizers without planter press wheel furrows and broadcast fertilizer application with furrows, it cannot be concluded whether fertilizer application would influence the effect of planter press wheel compaction on weed growth. No effect was found in the absence of fertilizers. In view of the data presented above, a negative interaction between the effects of fertilizer application and the comparatively small compaction caused by the planter press wheels is unlikely. In case a positive interaction took place, it would mean that the negative effect of band-placement of fertilizers on the total amount of weed growth, would have been greater in the absence of planter press wheel furrows.

Spatial distribution of weed growth in the presence of crops

In crop-weed competition studies at the same experimental farm (Chapters III, IV and V), it was found that at harvest, uncontrolled weed growth in groundnuts and soybeans was concentrated between the crop rows (Fig. 3).

The band-placing of the fertilizer near the rows gives the crop a competitive advantage over the weeds by limiting weed access to the applied nutrients, while allowing the crop good access to them. A comparatively rapid crop establishment and rapid canopy closure in the rows largely limited weed growth to between the rows. However, despite the advantage to the crop of having good access to the applied nutrients, with band-fertilized sorghum the reverse situation was found (Fig. 3). More weed growth was observed in the rows than between them. Due to the comparatively slow establishment and more open and thus less competitive canopy structure of sorghum, weed growth was concentrated where the fertilizers had been placed.

The considerably higher application of N fertilizer in sorghum (95 kg

ha^{-1}), compared with soybeans and groundnuts (18 kg ha^{-1}) - while weeds respond particularly well to N (Chapter VI) - will have accentuated the difference in spatial distribution of weed growth between the crops.

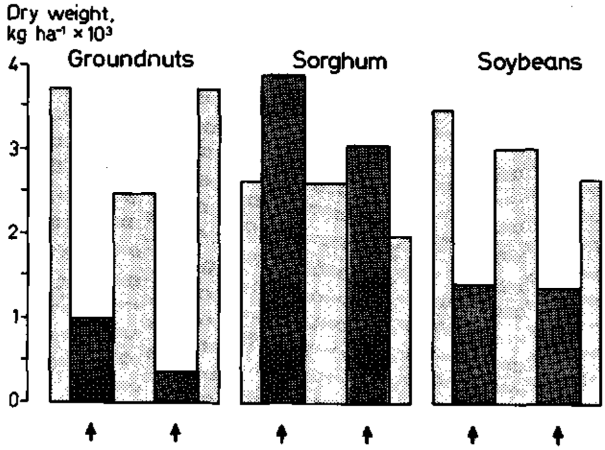

Fig. 3. Spatial distribution of uncontrolled weed growth at harvest in groundnuts, sorghum and soybeans (crop rows indicated by arrows).

Based on the results of the present observations, it can be expected that without adequate weed control in the three crops investigated, weed growth, and thus competition, would be more severe if fertilizers were broadcast rather than band-placed. It can be concluded that, especially on low fertility soils, apart from improving the efficiency of fertilizer application, placing fertilizers in a narrow band several centimetres deep can be an important tool in reducing weed growth and increasing crop competitiveness. Comparable conclusions were reached by Sánchez and Salinas (1981), based on observations by Spain (1978), who reported that because of their low fertility, Oxisols of tropical savannas in Columbia remain weed-free for several months after tillage if fertilizers are not applied. Competition with weeds is minimized by placing initial fertilizers only near the hill of planted grasses, with the area between the plants fertilized only after a good establishment has been obtained.

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Chapter VIII

CONCLUSIONS AND SUMMARY

The Zanderij area in Suriname is mainly covered by evergreen seasonal forest. For the most part, the area has a tropical rain forest climate (Köppen's classification). Its soils are predominantly sandy and of low fertility. In the 'sixties, when the Zanderij area was made accessible by a road system for timber exploitation, agricultural interest in the area developed. In 1969 and 1978, two experimental farms, Coebiti and Kabo, were established in the Zanderij area.

Despite the fact that Coebiti and Kabo were newly established in forested areas, a weed flora composed of species known in crops in other parts of Suriname rapidly built up with the cultivation of annual crops on these two farms. The frequent contact with agriculture in the coastal plain of Suriname and, in the case of Kabo, contact with Coebiti, was probably the major factor in this rapid build up.

In the period 1981 to 1984 at the Coebiti farm, a number of studies were made on the growth of weeds and crop-weed competition. The results of experiments with groundnuts, sorghum and soybeans (Table 1) indicated that, without adequate weed control significant yield losses, due to competition with weeds, occurred.

Table 1. Summary of experiments on crop-weed competition.

Crop, cultivar	Year	Season[1]	Soil	Main weeds
Groundnut,	1982	LLRS	Predom. sandy	*Eleusine indica, Physalis angulata, Euphorbia heterophylla*
Matjan	1982/83	SRS	Sandy loam	*Eleusine indica, Amaranthus dubius*
Sorghum,	1982	LLRS	Sandy loam	*Eleusine indica, Cenchrus echinatus*
Martin	1983	LLRS	Loamy sand	*Eleusine indica, Cenchrus echinatus, Croton hirtus*
Soybean,	1982	LLRS	Loamy sand to s.l.	*Eleusine indica, Euphorbia heterophylla, Physalis angulata*
Jupiter	1982/83	SRS	Sandy loam	*Digitaria* spp., *Cenchrus echinatus, Eleusine indica*

1) (LLRS = Late Long Rainy Season; = Short Rainy Season)

Competition with weeds did not affect plant density but reduced ground-cover and leaf area index of the crops, and affected growth rates, leading to lower yields.

Weeds competed for water in all three crops. Competition for nutrients was strong only in sorghum. In this case, to a large extent, the crop and weeds explored the same soil volume and competed for the applied nutrients which were band-placed near the row. During early crop growth, nitrogen appeared the nutrient most competed for. Competition for nutrients was absent in groundnuts. Here, the capacity of the crop for nitrogen fixation was not affected, thus avoiding the competition for nitrogen. Furthermore, the groundnuts and weeds probably explored partly different soil volumes, and the crop could take advantage of good access to nutrients band-placed near the row. In soybeans, competition for nutrients appeared to be limited. In only one of the two experiments was there any indication of reduced potassium availability and, in early crop growth, uptake of nitrogen was affected. There could be several reasons for this restricted competition for nutrients: the crop's capacity for nitrogen fixation, at least in the later crop growth stages, was not affected, thus avoiding competition for nitrogen; the crop and the weeds may have explored partly different soil volumes; the crop had better access to the band-placed nutrients than the weeds. Competition for light was observed in groundnuts and appeared likely in soybeans but unlikely in sorghum.

In groundnuts, about 15 weed-free DAP (Days After Planting) were sufficient to prevent yield losses due to competition with weeds or the presence of too much weed at harvest. Perhaps even shorter periods might have sufficed. Yield losses in sorghum were prevented with about 20 weed-free DAP. A period up to around 30 DAP was needed to attain negligible weed growth at harvest. It was necessary to weed soybeans for around 30 DAP to avoid yield loss and too much weed growth at maturity.

In groundnuts, yield loss due to weed competition was caused by a reduction in the number of pods per plant. To prevent yield loss, competition should be avoided during the period when the number of pods is determined, i.e. the period around 35 to 60 DAP. In sorghum, competition with weeds reduced yields primarily by decreasing the number of grains per panicle. In this crop, competition during the period of floret establishment, when the potential number of grains is determined, i.e. the period around 30 to 40 DAP, must be avoided. In soybeans, there were indications that absence of weed competition in the period of pod initiation, i.e. the period around 45 to 70 DAP, is critical to avoid yield reductions.

Uncontrolled weed growth in groundnuts and soybeans was mainly concentrated between the crop rows. In sorghum, on the other hand, more weed growth was found in the rows than between them. This spatial distribution of weed growth can be explained by the type of crop and the band-application of the fertilizers near the crop rows. The latter gives the crop a competitive advantage over the weeds by giving the crop good access to the nutrients applied, while limiting access to them for the weeds. Due to large seed size, groundnuts and soybeans have large seedlings, and rapidly establish some ground-cover. These crops develop a rather dense canopy structure which, in particular, quickly closes in the row and restricts the growth of weeds there. Sorghum, due to its much smaller seed size, is slower to establish some ground-cover and develops a rather open canopy structure which only shades the weeds to a limited extent. Despite the advantage to the crop of having good access to the nutrients applied, as a result of the crop characteristics, weed growth concentrates on the fertilizers placed near the row. In this case, this situation is accentuated by the low fertility of the soils.

In two studies concerning the effects of fertilizers on the growth of weeds (Table 2), it was observed that application of nitrogen increased the dry matter yield of weeds on a loamy sand, with a vegetation composed of species generally more commonly found on locations with a comparatively low fertility, as well as on a sandy loam, with a vegetation dominated by *Eleusine indica*, a species usually found on locations of comparatively high fertility.

Table 2. Summary of experiments on the effects of fertilizers on weed growth.

Type of experiment	Year	Season[1]	Soil	Main weeds
Effects of N, P and K	1983/84	SRS	Loamy sand	Mixed vegetation
	1983/84	SRS	Sandy loam	*Eleusine indica*
Fertilizer placement	1983/84	SRS	Loamy sand	Mixed vegetation
	1983/84	SRS	Sandy loam	*Eleusine indica*

1) (SRS = Short Rainy Season)

Response to phosphorus depended on the weed flora. Application of P stimulated growth of the vegetation dominated by *Eleusine indica*, but not of the other vegetation. In the case of the vegetation dominated by *Eleusine indica*, phosphorus interacted positively with nitrogen. Application of potassium increased weed density in both floras, but no response in weight was observed in either. Thus, the response of weeds to fertilizer application varies with the composition of the vegetation and the fertilizers applied.

Response of weeds to fertilizer application, in terms of weight, was considerably lower when the fertilizers were placed in a narrow band, several centimetres deep in planter press wheel furrows, when compared with fertilizers applied broadcast. With band-placed fertilizers, the increase in weed weight was concentrated on the fertilized bands.

Although the weeds in the annual crops could usually satisfactorily be controlled by using herbicides, to reduce the dependence on the exclusive use of chemicals in the control of weeds it is necessary to investigate if mechanical weed control, whether or not in combination with other methods, could be a feasible alternative. Decreasing planting distance in the rows or between them, while increasing or maintaining plant density, could add to crop competitiveness.

Hoofdstuk IX

CONCLUSIES EN SAMENVATTING

Het Zanderij gebied in Suriname is voor het overgrote deel met bos bedekt. Voor het grootste gedeelte kent deze regio een tropisch regenwoud klimaat (Köppen's classificatie). De voornamelijk zandige bodems hebben een geringe vruchtbaarheid. Toen in de jaren zestig het Zanderij gebied toegankelijk werd door een wegennet voor houtexploitatie, kwam de landbouwkundige interesse in deze regio tot ontwikkeling. In 1969 en 1978 werden er twee proeftuinen, te weten Coebiti en Kabo, aangelegd.

Hoewel deze proeftuinen werden aangelegd in bebost terrein, ontwikkelde zich met de teelt van éénjarige gewassen, op beide proeftuinen snel een onkruidflora, bestaande uit soorten bekend uit andere gedeelten van Suriname. Het veelvuldige contact met landbouw in de kustvlakte van Suriname, en in het geval van Kabo ook met Coebiti, is waarschijnlijk de belangrijkste factor geweest voor de snelle opbouw van deze onkruidflora op beide proeftuinen.

Van 1981 tot 1984 werd op de proeftuin Coebiti een aantal proeven uitgevoerd om de groei van onkruiden en de concurrentie tussen onkruiden en gewassen te onderzoeken. De resultaten van experimenten met aardnoot, sorghum en soja (Tabel 1) gaven aan, dat de opbrengst van deze gewassen zonder afdoende onkruidbestrijding, als gevolg van concurrentie met onkruiden, aanzienlijk werd verlaagd.

Tabel 1. Overzicht van de proeven betreffende gewas-onkruid concurrentie.

Gewas, ras	Jaar	Seizoen[1]	Grondsoort	Belangrijkste onkruiden
Aardnoot,	1982	THGR	Voorn. zandig	*Eleusine indica, Physalis angulata, Euphorbia heterophylla*
Matjan	1982/83	KR	Zandige leem	*Eleusine indica, Amaranthus dubius*
Sorghum,	1982	THGR	Zandige leem	*Eleusine indica, Cenchrus echinatus*
Martin	1983	THGR	Lemig zand	*Eleusine indica, Cenchrus echinatus, Croton hirtus*
Soja,	1982	THGR	Lemig zand tot z.l.	*Eleusine indica, Euphorbia heterophylla, Physalis angulata*
Jupiter	1982/83	KR	Zandige leem	*Digitaria* spp., *Cenchrus echinatus, Eleusine indica*

1) (THGR = Tweede Helft Grote Regentijd; KR = Kleine Regentijd)

Deze concurrentie leidde niet tot aantasting van de plantdichtheid van de gewassen, maar verlaagde de bedekkingsgraad en de z.g. leaf area index en tastte de groeisnelheid van de gewassen aan, hetgeen leidde tot lagere opbrengsten.

In alle drie gewassen concurreerden de onkruiden om water. Een duidelijke concurrentie om nutriënten werd alleen in sorghum gevonden. In dit gewas benutten gewas en onkruiden in belangrijke mate hetzelfde gedeelte van de bodem en concurreerden om de, naast de gewasrijen toegediende, nutriënten.

In de eerste fase van de groei van dit gewas leek de concurrentie om nutriënten zich op stikstof toe te spitsen. In aardnoot trad geen concurrentie om nutriënten op. In dit gewas werd de stifstofbinding door het gewas niet aangetast, waarmee concurrentie om stikstof werd vermeden. Daarnaast benutten het gewas en de onkruiden mogelijk voor een deel een verschillend gedeelte van de bodem, terwijl het gewas verder het voordeel had van goede toegankelijkheid tot de naast de gewasrijen toegediende nutriënten. Concurrentie om nutriënten tussen onkruiden en soja bleek beperkt. In slechts één van de twee proeven werden aanwijzingen voor concurrentie om kalium gevonden en werd de stikstofopname in de beginfase van de gewasgroei verminderd. Deze beperkte mate van concurrentie kan verschillende oorzaken hebben gehad. In de latere fasen van de gewasgroei werd de stikstofbinding door het gewas in elk geval niet verminderd, zodat concurrentie om stikstof werd vermeden. Evenals bij aardnoot, benutten gewas en onkruiden waarschijnlijk ten dele een verschillend gedeelte van de bodem en had het gewas beter toegang tot de naast de rijen toegediende nutriënten dan de onkruiden.

Aardnoot en onkruiden concurreerden om licht. Concurrentie om licht speelde waarschijnlijk ook een rol in de concurrentie tussen onkruiden en soja, maar leek niet van belang bij sorghum.

In aardnoot bleek onkruidvrij houden van het gewas gedurende een periode van ongeveer 15 DNZ (Dagen Na Zaai) voldoende om opbrengstderving als gevolg van concurrentie met onkruiden te voorkomen. Deze periode bleek tevens voldoende te zijn teneinde de aanwezigheid van teveel onkruid bij de oogst te vermijden. Kortere perioden zouden mogelijk dezelfde resultaten hebben kunnen opleveren. Opbrengstderving in sorghum als gevolg van concurrentie met onkruid werd voorkomen door het gewas ongeveer 20 DNZ onkruidvrij te houden. Tot ongeveer 30 DNZ onkruidvrij houden was nodig voor een verwaarloosbare hoeveelheid onkruid bij de oogst. Soja moest ongeveer 30 DNZ onkruidvrij worden gehouden om te voorkomen, dat er verlies van opbrengst optrad en er teveel onkruid bij de oogst aanwezig was.

In aardnoot werd opbrengstderving als gevolg van concurrentie met onkruid veroorzaakt door een vermindering van het aantal peulen per plant. Om opbrengstderving te voorkomen moet concurrentie gedurende de periode dat de peulen worden aangelegd, dat is van ongeveer 35 to 60 DNZ, worden vermeden. Opbrengstverlies bij sorghum als gevolg van concurrentie met onkruid werd voornamelijk veroorzaakt door een vermindering van het aantal korrels per pluim. Om opbrengstverlies te voorkomen moet concurrentie in de periode van ongeveer 30 tot 40 DNZ worden vermeden. In die periode wordt het aantal bloemen bepaald, waardoor het potentiële aantal korrels per pluim wordt vastgelegd.

In het geval van soja werden aanwijzingen gevonden, dat ter voorkoming van opbrengstderving concurrentie tijdens de periode van peulaanleg, dat is hier ongeveer van 45 tot 70 DNZ, moet worden vermeden.

De onkruidgroei in aardnoot en soja concentreerde zich voornamelijk tussen de gewasrijen. In sorghum werd meer onkruid in de gewasrijen gevonden dan er tussen. Deze ongelijke verdeling van de onkruidgroei vindt zijn oorzaak in het type gewas en in de plaatsing van de kunstmest naast de gewasrijen. Het laatste geeft de gewassen het voordeel van een goede toegankelijkheid tot de kunstmest, terwijl deze voor de onkruiden wordt beperkt. Aardnoot en soja hebben vrij grote zaden en vormen derhalve grote kiemplanten, waardoor al snel enige bodembedekking plaats vindt. Beide gewassen vormen een vrij gesloten bladerdek, dat zich vooral in de rijen snel sluit, waardoor onkruidgroei in de rij wordt belemmerd. Sorghum bezit vrij kleine zaden en vormt derhalve kleine kiemplanten, waardoor slechts langzaam enige bodembedekking ontstaat. Het gewas vormt vervolgens een vrij open bladerdek, dat onkruiden slechts in beperkte mate beschaduwt. Als gevolg hiervan concentreert de onkruidgroei zich op de kunstmest, die naast de gewasrij is toegediend, ondanks het voordeel voor het gewas van goede mogelijkheid tot opname van de toegediende kunstmest. In het geval van sorghum wordt de ongelijke verdeling van de onkruidgroei in en tussen de rijen nog versterkt door de geringe bodemvruchtbaarheid.

In twee proeven betreffende effecten van kunstmest op de groei van onkruiden (Tabel 2) werd gevonden, dat stikstof de groei van onkruiden stimuleerde. Dit was zowel het geval op een lemige zandgrond, met een onkruidvegetatie samengesteld uit soorten die gewoonlijk meer algemeen op plaatsen van geringe

Tabel 2. Overzicht van de proeven betreffende de invloed van kunstmest op onkruidgroei.

Onderwerp	Jaar	Seizoen[1]	Grondsoort	Belangrijkste onkruiden
Invloed van N, P en K	1983/84	KR	Lemig zand	Gemengde vegetatie
	1983/84	KR	Zandige leem	*Eleusine indica*
Kunstmest plaatsing	1983/84	KR	Lemig zand	Gemengde vegetatie
	1983/84	KR	Zandige leem	*Eleusine indica*

1) (KR = Kleine Regentijd)

bodemvruchtbaarheid worden gevonden, als op een zandige leemgrond, met een onkruidflora die overheerst werd door *Eleusine indica*, een soort die meestal op relatief rijkere plaatsen voorkomt. Fosfaat stimuleerde wel de groei van de door *Eleusine indica* gedomineerde vegetatie, maar niet die van de andere vegetatie. In het geval van de door *Eleusine indica* gedomineerde vegetatie werd tevens een positieve interactie tussen fosfaat en stikstof gevonden.

Toediening van kalium resulteerde bij beide onkruidvegetaties in een toename van het aantal planten, maar bij geen van beiden werd een toename in gewicht gevonden. De effecten van bemesting variëren dus met de samenstelling van de onkruidvegetatie en met de toegediende nutriënten.

De toename in gewicht van onkruiden bij bemesting was aanzienlijk minder groot wanneer de kunstmest in een smal strookje, enige centimeters diep, in de geulen van de aandrukwielen van een zaaimachine werd geplaatst, dan wanneer de kunstmest breedwerpig werd uitgestrooid. Met de kunstmest toegediend in een smal strookje was de toename in gewicht op de bemeste strookjes geconcentreerd.

Hoewel de onkruiden in de éénjarige gewassen gewoonlijk afdoende konden worden bestreden met herbiciden, is het, om de afhankelijkheid van uitsluitend chemische onkruidbestrijding te verminderen, noodzakelijk te onderzoeken of mechanische onkruidbestrijding een haalbaar alternatief is, al dan niet in combinatie met andere methoden. Vermindering van de afstand in of tussen de rijen, bij toenemende of gelijkblijvende plantdichtheid, kan de concurrentiekracht van het gewas verhogen.

Curriculum vitae

Arij Pieter Everaarts werd op 1 mei 1950 geboren te Maassluis. Van 1967 tot 1975 studeerde hij Tuinbouwplantenteelt aan de Landbouwhogeschool te Wageningen, met als doctoraal vakken de Tuinbouwplantenteelt, de Plantenfysiologie en de Plantensystematiek en -geografie van de tropen en subtropen. Het laatste vak werd bewerkt op het Rijksherbarium te Leiden. In 1972 bracht hij zijn praktijktijd in Indonesië door.

Van 1975 tot 1979 werkte hij in Indonesië als assistent-deskundige in een Nederlands-Indonesisch agrarisch samenwerkingsproject. Na terugkomst in Nederland was hij tot 1980 te gast op het Rijksherbarium, waar hij werkte aan een publicatie over onkruiden in de hoogland groenteteelt op Java.

In 1981 trad hij in dienst van de Landbouwhogeschool. Van 1981 tot eind 1984 verrichtte hij in Suriname het veldwerk van het in dit proefschrift beschreven onderzoek.

Sinds 1987 is hij werkzaam bij de afdeling Teeltonderzoek Groenten van het Proefstation voor de Akkerbouw en de Groenteteelt in de Vollegrond te Lelystad.