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Effects of competition with weeds on growth, development and yield of soybeans

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Abstract

Two field experiments were carried out to study competition between soybeans (*Glycine max* (L.) Merr.) and weeds. The crop was kept weed-free or without weed control for increasing periods of time after planting. An analysis of the growth and development of a crop with weed control and of a crop without weed control, was obtained by making observations at the end of each period of time with or without weed control. Uncontrolled weed growth concentrated mainly between the rows. Competition with weeds reduced ground-cover and leaf area index of the crop, leading to a lower weight and yield. Plant density was not affected, but weed competition reduced the number of branches, inflorescences, and pods per plant. Timing of flowering was not influenced. Competition for water was inferred and competition for light seemed likely. Competition for nutrients was weak. Weeding in the period of pod initiation, i.e. around 45 to 70 days after planting, appeared to be essential to avoid competition with weeds. A period of around four weed-free weeks after planting was necessary to avoid yield reduction or too much weed growth at harvest.

Keywords : soybeans, *Glycine max*, weed competition, growth analysis, nutrient uptake, pod initiation, distribution of weed growth, humid tropics, Suriname

Introduction

In many tropical countries average soybean (*Glycine max* (L.) Merr.) yields are low (FAO, 1986). Data in the literature indicate that substantial yield losses can occur due to inadequate weed control (Waranyuwat & Kotama, 1973; Bhan et al., 1974; Sistachs & Leon, 1975; Blanco et al., 1978; Eissner et al., 1984; Fageiry, 1987).

The degree of competition between crop and weeds is influenced by plant density (Nangju, 1980), row spacing (Hammerton, 1972; Nangju, 1980), cultivar

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(Nangju, 1980; Durigan et al., 1983), season (Thomas & van Lindert, 1980), soil moisture conditions (Watanabe et al., 1981) and some other factors. The presence of weeds may affect seed quality (Dhingra & da Silva, 1978; Nangju, 1980). Eiszner et al. (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.

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 soybeans on sandy loam soils in the inland region of Suriname (Janssen & Wienk, 1990). In the framework of this interest the effects of weeds on soybean growth and yield were studied.

In this paper, the results of two experiments on the effects of weeds on growth, development 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 (5°20′ N, 55°30′ W), during the late long rainy season of 1982 on a loamy sand to sandy loam soil (Experiment 1) and during the short rainy season of 1982-83 on a sandy loam soil (Experiment 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 and potential evapotranspiration during the experiments are presented in Figure 1. Potential evapotranspiration of the crop was calculated as free water evaporation × crop coefficient. Free water evaporation was calculated according to the Penman formula, as amended by Doorenbos & Pruitt (1977). Based on crop development and the indications given by Doorenbos & Pruitt (1977), the crop coefficient was taken as 0.45 during the first 20 days after planting (DAP), subsequently increasing linearly to 1.00 at midseason (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 (Experiment 1) and 400 kg ha^{-1} Ca (Experiment 2). Seeds were machine-planted in rows, 0.5 m apart, at 0.07 (Experiment 1) or 0.06 (Experiment 2) m in the row, immediately after disc-harrowing, ploughing and harrowing. Open plant spaces were replanted at emergence. Seedlings were thinned where necessary to an average distance of 0.10 m in the row, leading to densities of 148 000 (Experiment

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

	Experiment 1	Experiment 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
A1, mmol (+) kg^{-1}	3.3	6.6
ECEC[1], mmol (+) kg^{-1}	14.3	21.8
100 × exch. A1/ECEC	23	30
CEC[2], pH7, mmol (+) kg^{-1}	27.0	34.0
P-Bray I, mg kg^{-1} P	30.4	25.7

[1]ECEC = Effective Cation Exchange Capacity.
[2]CEC = Cation Exchange Capacity.

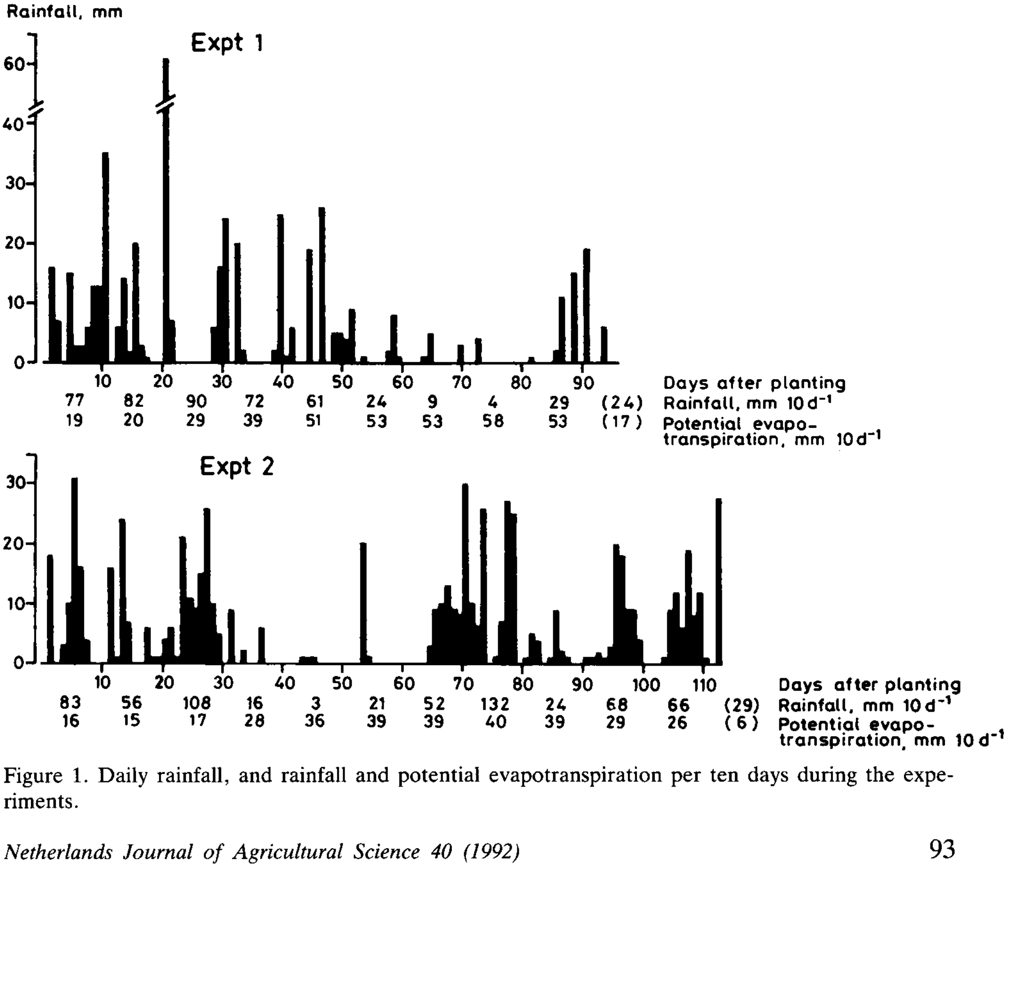

Figure 1. Daily rainfall, and rainfall and potential evapotranspiration per ten days during the experiments.

1, 25 DAP) and 186 500 (Experiment 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 (Experiment 1) and 113 (Experiment 2) DAP.

Experimental procedures

The experimental design consisted of twelve (Experiment 1) or fourteen (Experiment 2) treatments in a randomized complete block design, replicated five times. In one series of six (Experiment 1) or seven (Experiment 2) treatments the crop was kept free of weeds, by hand-weeding, for increasing periods of time from planting onwards, after which weed growth was permitted. In the other series, weed growth was not controlled for the same six or seven periods of time after planting as above, after which time the crop was kept weed-free until harvest.

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, leaf-discs, 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 was established as above,
- In the treatments with weed growth after planting two 0.5 × 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.
- In Experiment 2 the spatial distribution of weed growth at harvest was studied in the plots without any weed control. A sample of 1 × 1 m, divided in five strips of 0.125, 0.25, 0.25, 0.25 and 0.125 m wide, was taken of the weed vegetation lengthwise over the crop row.

The combination of observations at the end of each period with or without weed control after planting provided an analysis of the growth and development of a crop with and without weed control. 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 (Figure 2). In Experiment 1, ground-cover declined sharply thereafter, irrespective of treatment, because of wilting and leaf-fall as a result of drought (Figure 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.

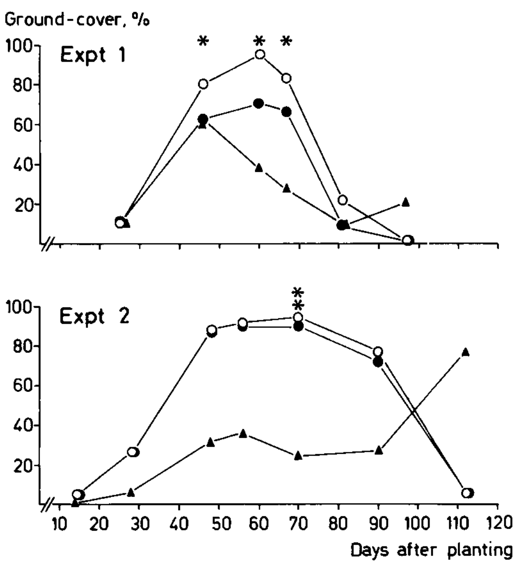

Figure 2. Ground-cover of the crop with (○) and without (●) weed control and of the weed vegetation (▲). Following a one-sided *t*-test a significant difference between treatments is indicated by * ($P \leq 0.05$) or ** ($P \leq 0.01$).

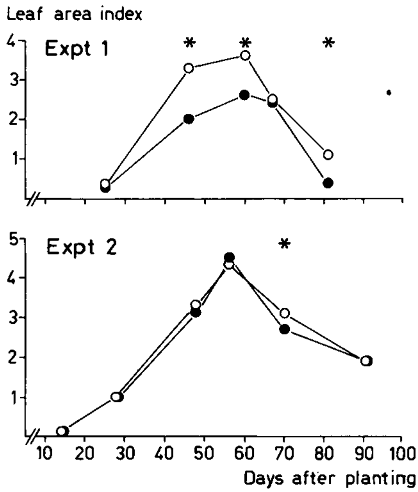

Figure 3. Leaf area index of the crop with (○) and without (●) weed control. Following a one-sided *t*-test a significant difference between treatments is indicated by * ($P \leq 0.05$).

Maximum LAI values in both experiments were reached around 50 to 60 DAP (Figure 3). In Experiment 1 from day 25 onwards, 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. The severe drought later in this experiment accelerated the decline in LAI, irrespective of treatment, because of leaf-fall resulting from the drought.

Dry weight

In Experiment 1, the reduced ground-cover and LAI of the crop without weed control resulted in a reduced assimilate supply. In this experiment the increase in dry weight of the non-weeded crop was affected between 25 and 46 DAP (Figure 4). Weight of the stems was affected first. Stem weight relative to total 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 onwards, severe moisture stress impaired crop growth, in particular in the non-weeded treatments. 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 weight of the crop with and without weed control were small (Figure 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.

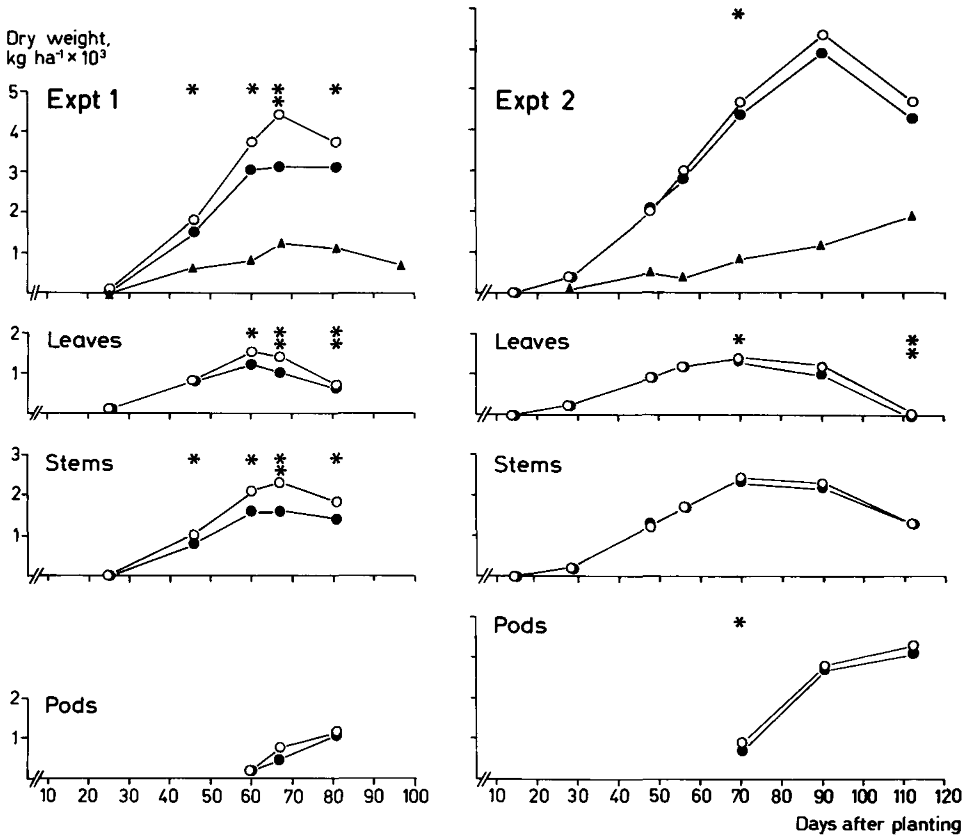

Figure 4. Dry weight (above-ground parts) of the crop with (○) and without (●) weed control and of the weed vegetation (▲, above-ground parts). Following a one-sided t-test a significant difference between treatments is indicated by * ($P \leqslant 0.05$) or ** ($P \leqslant 0.01$).

Development

Plant density was not consistently affected in either experiment (Table 2). 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 in the non-weeded crop and the same tendency was observed in Experiment 2 (Table 3). The reduction in stem weight observed in Experiment 1 (Figure 4) must partly be

Table 2. Development of the crop with and without weed control.

		Days after planting						
Experiment 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**
Length 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
Experiment 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 *($P \leq 0.05$) or by **($P \leq 0.01$).

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 % 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 3). 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.

The data from Experiment 1 suggest an increase in the number of pods per inflorescence in the non-weeded crop. This effect would partly compensate for the 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 presu-

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

		Days after planting						
Experiment 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
Experiment 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 *($P \leq 0.05$) or **($P \leq 0.01$).

mably on the timing and degree of competition.

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 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 % in the weed-free crop, and 15 and 18 % 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 makes a yield reduction or induction of differences between treatments unlikely. Studies made in South Carolina (Turnipseed, 1972), showed that 17 % defoliation at any growth stage did not cause significant yield losses.

Nature of competitive effects

Nutrients

In Experiment 1, the uptake of N, P and K by the non-weeded crop was consi-

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						
Experiment 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
Experiment 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 **($P \leq 0.01$).

derably lower when compared with the weed-free crop (Table 4).

The significantly lower N concentration at 25 DAP in the crop without weed control (Table 5), 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

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						
Experiment 1		25	46	60	67	81	97
N Crop weed-free		41.3	32.7	27.4	27.7	26.1	–
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
P Crop weed-free		3.5	3.0	2.6	2.5	2.8	–
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
K Crop weed-free		36.0	28.7	22.6	19.5	19.6	–
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
Experiment 2	14	28	48	56	70	90	112
N Crop weed-free	60.5	44.0	22.0	21.1	22.0	22.5	29.5
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
P Crop weed-free	5.6	3.8	3.2	3.2	2.7	2.1	3.0
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
K Crop weed-free	38.5	32.4	28.5	28.0	22.5	18.1	17.3
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 **($P \leq 0.01$).

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 growth, does not occur because 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.

Light

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 2).

Water

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.

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 (Figure 1). In view of the probably higher evapotranspiration of the non-weeded crop and weeds combined, 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 (Figures 2, 3 and 4) between the crop with and without weed control.

Conclusion

Competition between soybeans and weeds was mainly for light and water, the latter depended on rainfall. Competition for nutrients occurred, but was likely of limited importance. Comparable results were found in Zimbabwe. With adequate rainfall, competition between soybeans and weeds was mainly for light (Thomas & 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.

Yield

Weed-free period after planting

Yields (Table 6) 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 were found at harvest in the other treatments. Weed growth was, however, affected by the drought.

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

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

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).

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 6). 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 & Leon (1975) found yield reduction with competition up to 30 days after planting. On average of four seasons, Thomas & 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 & van Lindert (1980) found a reduction in some cases of more than 75 % 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 3) and weight per seed (Table 6). As to how far a reduced number of seeds per pod could have contributed to the lower yields was not investigated. In 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 & Ritter, 1987). Moisture stress did not appear to influence number of seeds per pod (Villalobos-Rodriguez & Shibles, 1985).

Although weed growth adversely affects early growth (Figure 4) and development (Tables 2, 3) 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 3), yield potential was irreversibly affected, and the plants could no longer compensate. With competition up to 67 DAP (Experiment 1) and 56 DAP (Experiment 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 6) 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 3), 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 & Ritter, 1987) to four (five) weeks after planting (Burnside, 1979; Horn & Burnside, 1985), may imply avoidance of

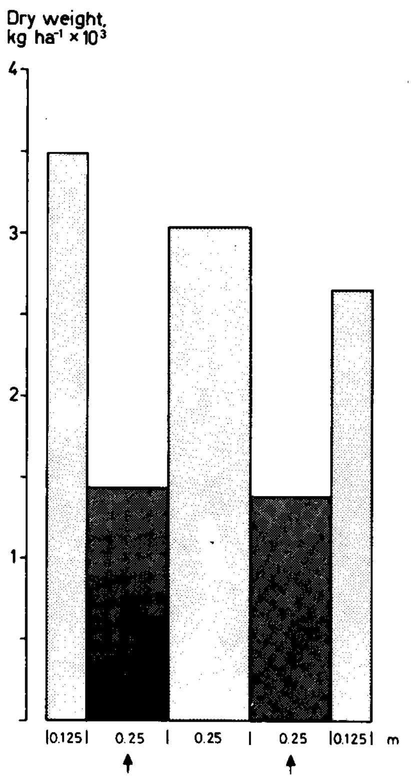

Figure 5. Spatial distribution of uncontrolled weed growth at harvest (Experiment 2; crop rows indicated by arrows)

competition during pod initiation. Based mainly on data from temperate areas, van Heemst (1985) estimated the critial period for crop-weed competition in soybean as from 0.12 up to 0.30 of the total crop growth period.

Spatial distribution of weed growth

In Experiment 2, weed growth at harvest appeared to be largely concentrated between the crop rows (Figure 5). The band-placement of the fertilizers ensured that the crop had good access to the nutrients applied, while limiting access to the weeds (Everaarts, 1991). 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 the rows limited weed growth in the row. Under the same conditions, a similar distribution of weed growth was found in groundnuts (Everaarts, 1992). With sorghum, however, more weed growth was found in the rows than between them, mainly due to the more open canopy structure of this crop (Everaarts, 1991).

Practical implications

It is 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 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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References

Bhan, V.M., Megh Singh & R.A. Maurya, 1974. Studies on the requirements of weedfree maintenance in soybean. *Indian Journal of Weed Science* 6: 12-16.

Blanco, H.G., D.A. Oliveira & J.B.M. Araujo, 1978. Critical competition period of a natural weed community in soybean (*Glycine max* (L.) Merr.). (In Portugese). *O Biológico* 44: 299-305.

Boxman, O., D. Goense, B.H. Janssen, J.J. Neeteson & J.F. Wienk, 1985. The effect of moisture stress on the response to nitrogen by maize in the humid tropics of Suriname. In: B.T. Kang & J. van der Heide (Eds), Nitrogen management in farming systems in humid and subhumid tropics, p. 199-214. IB, Haren; IITA, Ibadan.

Burnside, O.C., 1979. Soybean (*Glycine max*) growth as affected by weed removal, cultivar, and row spacing. *Weed Science* 27: 562-565.

Dhingra, O.D. & J.F. da Silva, 1978. Effect of weed control on the internally seedborne fungi in soybean seeds. *Plant Disease Reporter* 62: 513-516.

Doorenbos, J. & W.O. Pruitt, 1977. Crop water requirements. FAO Irrigation and drainage paper 24. FAO, Rome, 144 pp.

Dubey, S.K., H.C. Jain, L.D. Kosta & J.S. Raghu, 1984. Integrated weed management in soybean. *Indian Journal of Weed Science* 16: 238-243.

Durigan, J.C., R. Victoria Filho, T. Matuo & R.A. Pitelli, 1983. Weed competition periods in the soybean (*Glycine max* (L.) Merril) crop, Santa Rosa and IAC-2 cultivars. I. Effects on the yield parameters. (In Portugese). *Planta Daninha* 6: 86-100.

Eissner, H., J. Pohlan, C. Pérez, A. Ravelo & R. Rodríguez, 1984. Influence of weeds on the yield of soybean (*Glycine max* (L.) Merrill) at different plant densities. (In Spanish). *Centro Agrícola* 11: 11-18.

Eiszner, H., G. Franke & J. Pohlan, 1986. Demonstration of the competitive effects between soybean (*Glycine max* (L.) Merr.) and weeds in the soybean cultivation in Cuba. (In German). *Beiträge zur Tropischen Landwirtschaft und Veterinärmedizin* 24: 133-142.

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

Everaarts, A.P., 1992. Effects of competition with weeds on growth, development and yield of groundnuts. *Netherlands Journal of Agricultural Science* 40: 73-90.

Fageiry, K.A., 1987. Weed control in soybean (*Glycine max*) in Vertisols of Sudan. *Tropical Pest Management* 33: 220-223.

FAO, 1986. FAO Production Yearbook, 40. FAO, Rome.

Fortanier, E.J., 1962. Report of research on the possibilities of cultivation of secondary crops and tree crops in the Wageningen-project, Suriname. (In Dutch). Wageningen, Netherlands, 188 pp.

Hammerton, J.L., 1972. Effects of weed competition, defoliation and time of harvest on soyabeans. *Experimental Agriculture* 8: 333-338.

Harris, T.C. & R.L. Ritter, 1987. Giant green foxtail (*Setaria viridis* var. *major*) and fall panicum (*Panicum dichotomiflorum*) competition in soybeans (*Glycine max*). *Weed Science* 35: 663-668.

Heemst, H.D.J. van, 1985. The influence of weed competition on crop yield. *Agricultural Systems* 18: 81-93.

Horn, P.W. & O.C. Burnside, 1985. Soybean growth as influenced by planting date, cultivation, and weed removal. *Agronomy Journal* 77: 793-795.

Janssen, B.H. & J.F. Wienk (Eds), 1990. Mechanized annual cropping on low fertility acid soils in the humid tropics. A case study of the Zanderij soils in Suriname. Wageningen Agricultural University Papers 90.5, 230 pp.

Meulen, J.G.J. van der, 1955. Soybean trials on clay soils in the young coastal plain. (In Dutch). *De Surinaamse Landbouw* 3: 249-267.

Nangju, D., 1980. Effect of plant density, spatial arrangement, and plant type on weed control in cowpea and soybean. In: I.O. Akobundu (Ed.), Weeds and their control in the humid and subhumid tropics, p. 188-199. International Institute of Tropical Agriculture, Ibadan.

Sistachs, M. & J.J. Leon, 1975. Critical period of weed competition on soybean (*Glycine max* (L.) Merrill). *Cuban Journal of Agricultural Science* 9: 237-241.

Thomas, P.E.L. & H.J.A. van Lindert, 1980. Competition between mixed weeds and soya-beans in Zimbabwe. *Zimbabwe Agricultural Journal* 77: 215-219.

Turnipseed, S.G., 1972. Response of soybeans to foliage losses in South Carolina. *Journal of Economic Entomology* 65: 224-229.

Villalobos-Rodriguez, E. & R. Shibles, 1985. Response of determinate and indeterminate tropical soybean cultivars to water stress. *Field Crops Research* 10: 269-281.

Waranyuwat, A. & P. Kotama, 1973. Influence of plant population and weed control on soybeans. *Thai Journal of Agricultural Science* 6: 101-113.

Watanabe, Y., C. Nordsomboon & V. Sasiprapa, 1981. Effect of period of weed removal on growth and yield of mungbeans and soybeans in the Central Plain of Thailand. *Weed Research (Japan)* 26: 96-103.