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Research Article

Timing of weed management and yield penalty due to delayed weed management in soybean

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INFORMATION ARTICLE

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

HIGHLIGHTS

- Weed infestation for the first 14 days had no effect on soybean yield if the weeds were removed thereafter.
- Weeds, when not controlled throughout the season, resulted in 53-56% yield loss.
- Critical weed-free period was between 14 and 42 days after sowing.

ABSTRACT

Background: Weed interference is a major limiting factor for economically viable soybean production. Appropriate timing of weed management would enable farmers to make more efficient use of resources for weed management.
Objective: The objective of this study was to determine the critical period for weed competition and appropriate timing of weed management for optimum yield of soybean.
Methods: The treatments consisted of periods of weed infestation and weed removal for the first 14, 28, 42 and 56 days after sowing (DAS), and till harvest in a randomized complete block design with three replications in 2016 and 2017.
Results: Soybean yields in both years ranged from 914-945 kg ha^{-1} with no weed control to 1,984-2,127 kg ha^{-1} in the weed-free plots; a yield loss of 53-56%. Weed infestation for the first 14 DAS had no detrimental effect on growth and yield of soybean provided the weeds were subsequently removed. Increasing period of weed interference from 14 to 42 DAS resulted in a steady decline in growth and yield of soybean. Yield losses equivalent of 32-37 kg ha^{-1} resulted for each day that weed control was delayed between 14 and 42 DAS. Subsequent weed control after 42 DAS did not improve growth and yield significantly, nor obviate yield depression of the crop compared to crop weed-infested till harvest.
Conclusions: Results indicated that the critical period of weed competition in soybean was between 14 and 42 DAS. Hence soybean should be maintained weed-free during this period to avoid high yield loss.

1 INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is the most important legume crop globally, with a harvested area of 118 million ha and total production of 308 million Mg (FAOSTAT, 2017), accounting for 56% of total global oil seed production (Wilson, 2008). Soybean is a major component of global food security as a source of protein for human food and animal feed, and oil for cooking and biofuel (Abate et al., 2012). In Sub Saharan Africa (SSA), soybean is a major crop, largely grown by small-scale farmers because of its increasing importance in farming systems and daily diet of human populations (Khojely et al., 2018). Compared with other crops, soybean present a feasible alternative to addressing malnutrition in SSA because of its high protein, oil content and essential amino acids (Joubert and Jooste, 2013). It also has ability in fixing nitrogen (44-103 kg ha^{-1}) for its own use and the benefit of intercropped cereals and subsequent crop in rotation (Ronner et al., 2016). This is a major benefit in Africa farming systems, where soils have become exhausted by the need to produce more food for increasing populations, and where fertilizers are hardly available and are expensive for farmers.

Soybean production in SSA has increased dramatically by 177-fold, from 13,000 tons in the early 1970s to 2.3 million tons in 2016 due to substantial growth in planting area (Khojely et al., 2018). Nigeria is the second largest producer of soybean in SSA. However, consumption growth has out-paced domestic production growth with yield stagnated at 960 kg ha^{-1}, leaving a supply gap of more than 1.5 million tons (Khojely et al., 2018). One of the major constraints to high soybean yield in Nigeria is weed interference (Imoloame, 2014; Daramola et al., 2019). The losses caused by weeds exceed the losses from any other category of damage like insect, pest and diseases (Oerke and Dehne, 2004). Weeds compete with soybean for growth resources such as water Light and nutrients; causing yield loses up to 90% (Imoloame, 2014).

Smallholder farmers in Nigeria control weeds in soybean predominately by manual weeding. However, labor shortage and its high cost is a major constrain (Chikoye et al., 2007). Although the use of herbicides is efficient, they do not provide season-long weed control when used alone, and single herbicide application may not control the entire weed spectrum (Adigun et al., 2017). In addition, herbicides for weed control in soybean are expensive and often not available to smallholder farmers at the time of need and, when available, farmers lack the requisite knowledge and skill to use herbicides correctly. Although herbicide use alleviates the problem of labor for weeding, incorrect use may bring about other environmental problems (Labrada, 2002). The number of manual weeding and the amount of herbicides used could be reduced if their timing is based on the critical period of weed control (CWCP); this is the interval during which weeds have the greatest impact on crop growth and yield (Knezevic et al., 2003). Weeds that emerge before or after the CPWC may not represent a threat to crop yield, but weed infestation during the CPWC results in irrevocable yield reduction (Adigun et al., 2017). Appropriate timing of weed control during the CPWC therefore, will help growers to effectively use the available resources. Although the impact of weed interference on crop yield and productivity are well documented, appropriate timing and the duration of weeding required to achieve minimum weed competition and optimum yield of soybean is still poorly understood. A clear understanding of the period at which soybean is most sensitive to weed interference will help to make appropriate decisions on the timing of weed management. This study was therefore carried out to evaluate growth and yield response of soybean to different periods of weed interference and timing of weed control.

2 Materials and Methods

Two field studies were carried out at the Institute of Food Security Environmental Resources and Agricultural Research located at latitude 7° 15’ N and longitude 3°25’ E in south western Nigeria in 2016 and 2017. During this period, total rainfall was 667 and 545 mm, minimum temperature was 22.1 and 23.0 °C and maximum temperature was 25.0 and 27.0 °C, in 2016 and 2017, respectively. The soil of the study sites was sandy-loam with pH 7.9 and 7.4, total nitrogen of 0.2 and 0.16% and organic matter of 2.4 and 2.1% in 2016 and 2017, respectively. The study site was cleared manually while ploughing and harrowing were done mechanically at two weeks’ interval. Soybean seeds were sown manually at inter-row spacing of 75 cm and intra row spacing of 10 cm. The gross plot size was 13.5 m^2 while the net plot size was 9 m^2. The soybean variety “TGX 1448-2E” used in this study is semi-determinate, late maturing (115-120 days) and high yielding (1-7-2.3 tons ha^{-1}) with good nodulation (Tefera, 2011).

Ten treatments (WI_{14}-WF_{har}) (Table 1) were used to examine the effects of different period of interference and timing of weed control in both years. The treatments consisted of periods when the crop was allowed to be infested with weeds for the first 14, 28, 42 and 56 days after sowing (DAS), and periods when the weeds were removed (weed-free) for the first 14, 28, 42 and 56 DAS. Two treatments of weed infestation and weed removal till harvest were also included as the checks in a randomized complete block design with three replications. Weed growth was controlled in the required periods for each of the treatments, and hand weeding was done at weekly intervals as applicable. The term “weed-free” in the treatments therefore indicates the period during

Table 1 - The details of period of weed interference treatments

Treatment	Details
WI_{14}	Weed-infested until 14 days after sowing (DAS)
WI_{28}	Weed-infested 28 DAS
WI_{42}	Weed-infested 42 DAS
WI_{56}	Weed-infested 56 DAS
WI_{har}	Weed-infested from sowing till harvest
WF_{14}	Weed-free until 14 DAS
WF_{28}	Weed-free until 28 DAS
WF_{42}	Weed-free until 42 DAS
WF_{56}	Weed-free until 56 DAS
WF_{har}	Weed-free from sowing till harvest

which weeds were removed at weekly intervals. Weed cover score, weed density (m^{-2}) and dry weight ($g\ m^{-2}$), crop vigor score, canopy height (cm), number of leaves and branches, leaf area index, number of pods and seeds per plant, pod and seed weight per plant (g), 100 seed weight (g) and seed yield (kg) were used to evaluate the treatments in both years.

All soybean growth parameters were taken at 80 DAS in both years. Weed cover score for each treatment was evaluated by visual observation before weed removal based on scale of 1-10, where 1 represent complete weed-free situation while 10 represent complete weed cover (Adigun et al., 2017). Weeds were sampled from a 1 m^2 quadrat placed randomly at three spots within each plot at 14, 28, 42, 56 DAS and at harvest, with weeds cut at ground level. Weed density (m^2) was taken by counting the weed species. The weeds were oven-dried at 70 ^oC for 72 hours and the weed dry weight recorded in kg ha^{-1}. Crop vigor score was by visual rating at 80 DAS on scale 0-10, where 0 represented plots with dead or least vigorous crops while 10 represented plots with the most vigorous crop (Nikoa et al., 2015). Soybean dry weight was determined from five plants at 80 DAS by destructive sampling within the net plot. The plants were uprooted and then oven-dried at 70 ^oC for 72 hours. Crop growth rate was calculated as proposed by Hunt (1989), as indicated below:

$$crop\ growth\ rate = \frac{W2 - W1}{T2 - T1}$$

where W1 and W2 are values of dry weight at times T1 (42 DAS) and T2 (84 DAS), respectively. Leaf area index (LAI) was calculated at 80 DAS following the formula of Watson (1947) as follows:

$$LAI = \frac{Leaf\ area\ per\ palnt\ (cm^2)}{Ground\ area\ per\ plant\ (cm^2)}$$

Leaf area was determined at 80 DAS from five randomly selected tagged plants within the net plots by measuring the length (L) and width (W) of the terminal leaflet and multiplying the product with the leaf shape correction factor. The total leaf area per plant was then calculated following the procedure outlined by Wiersma and Bailey (1975) using the derived equation: $A = 0.411 + 2.00\ LW$, where A is leaf area and L and W are the length and width of the terminal leaflet of a trifoliate leaf respectively. 0.411 and 2.00 are constants. Soybean was harvested manually when 95% of plants had around 90% mature pods. Grain yield from each plot was recorded in kg ha^{-1}. Data were subjected to analysis of variance (ANOVA) using GENSTAT package. Means were compared with Turkey's honest significant difference ($P \leq 0.05$).

3 Result and Discussion

3.1 Weed cover score, weed density and dry weight as affected by different periods of weed interference and timing of weed control

Fifteen (15) weed species were recorded during the period of crop growth in both years. The weed species comprised of 7 broadleaf weeds, 6 grasses and 1 sedge (Table 2). The prevalence of both annual and perennial broadleaved weeds and grasses in this study may be as a result of high disturbance environment that favor them (Menalled et al., 2001). The weed species were generally more abundant in the 2017 than in 2016. *Commelina benghalensis*, *Gomphrena celozoides*, *Euphorbia heterophylla*, *Panicum maximum* and *Digitaria horizontalis* which had high infestation in 2017 were found with moderate infestation in the 2016 (Table 2). This was possibly because of more evenly distribute rainfall experienced in 2017 than in 2016 (Figure 1). It has been reported that rainfall affects weed species distribution and their competitiveness within a weed community (Daramola et al., 2019).

In both years, period of weed interference significantly affected weed cover score, weed density and dry weight (Table 3). Weed cover score increased significantly as the period of weed infestation increased and *vice versa* as the period of weed removal increased from 14 DAS until harvest in both years (Table 3). Weed density and dry weight increased significantly as the period of weed infestation increased from 14 until 42 DAS in both years. Thereafter, there was no significant increase in weed density and dry weight with increasing period of weed infestation till harvest (Table 3). Weed density and dry weight were similar between the plots where weeds were allowed to grow until 14 DAS (WI_{14}), and

Table 2 - Weed species and their level of infestation during the period of crop growth in 2016 and 2017

Weed species	Plant family	Level of infestation	
		2016	2017
Broad leaf weeds			
Tridax procumbens (Linn).	Asteraceae	***	***
Euphorbia heterophylla (Linn).	Euphorbiaceae	**	***
Commelina benghalensis (Burn.)	Commelinaceae	**	***
Gomphrena celozoides (Mart.)	Amaranthaceae	**	***
Spigelia anthemia (Linn).	Loganiaceae	*	**
Boerhavia 4ifusa (Linn).	Nyctaginaceae	*	**
*Chromoleana odorata (*L.) R.M. King and Robinson	Asteraceae	-	**
Grasses			
Digitaria horizontalis (Willd.)	Poaceae	**	***
Panicum maximum (Jacq)	Poaceae	**	***
Axonopus compressors (Sw.) P. Beauv	Poaceae	-	**
Rottboellia conchinchinensis (Lour.) Clayton	Poaceae	**	**
Eleusine indica(Gaertn)	Poaceae	-	*
Cynodon dactylon (L) Gaertn	Poaceae	***	***
Sedge			
Cyperus rotundus	Cyperaceae	**	**
Cyperus esculentus	Cyperaceae	**	**

*** Highly infested (60-90); ** Moderately infest (30-59%); * Low infestation (1-29%); - not noticeable.

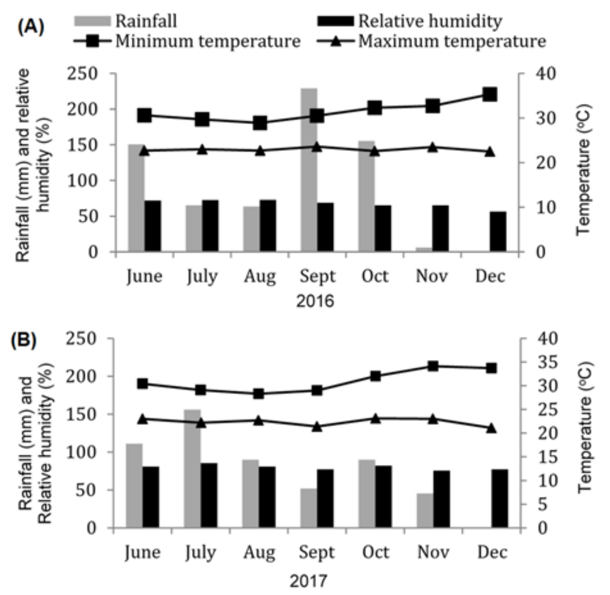

Figure 1 - Meteorological data during the period of crop growth, in 2016 (A) and 2017 (B).

where weeds were controlled until 42 DAS (WF_{42}), 56 DAS (WF_{56}) and harvest. However, allowing weeds to infest the crops until 28 DAS or longer significantly increased weed density by 54 - 126% and weed dry matter by 50 - 115% compared with plots kept weed-free till harvest (WF_{har}). Plots kept weed-free until 14 DAS (WF_{14}) and those weed-infested until 42 DAS (WI_{42}), 56 DAS (WI_{56}) and harvest (WI_{har}) had similar weed density and dry weight in both years (Table 3). This trend suggests that rapid weed growth and critical weed-crop interference was between 14 and 42 DAS. This may be attributed to the fact that weeds were not yet well established before 14 DAS, and after 42 DAS, soybean canopy closure enhanced the suppression of late emerging weeds. After soybean canopy closure, there was apparently no further weed infestation for the remaining period of crop growth. This result is in agreement with the report of Osipitan et al. (2016) in cowpea, that if weeds are controlled with the first 6 weeks of crop growth, the crop canopy can suppress late-emerging weeds.

3.2 Growth and yield of soybean as affected by different periods of weed interference

With exception of number of seeds per pod, period of weed interference had significant effect on all the growth and yield parameters of soybean in both years (Tables 4 and 5). Plots where weeds were allowed to grow until 14 DAS (WI_{14}) and those kept weed-free until harvest (WF_{har}) had similar crop vigor, canopy height, number of leaves and branches, leaf area index, crop growth rate, number of pods and seeds per plant, pod and seed weight per plant, 100 seed weight and grain yield in both years (Tables 4 and 5). These parameters were similar between plots kept weed-free for only 14 DAS (WF_{14}) and those where weeds were allowed to grow till harvest (WI_{har}) in both years (Tables 4 and 5). This showed that weed infestation for the first 14 DAS had no detrimental effect on growth and yield of soybean provided the weeds were subsequently removed. On the other hand, weed control for only 14 DAS did not obviate growth and yield reduction compared to crop weed-infested till harvest. This result indicate that soybean could tolerate weed competition until 14 DAS,

Table 3 - weed cover score, weed density and dry weight as influenced by period of weed interference in soybean in 2016 and 2017

Weed interference(1)	Weed cover score		Weed density (m^{-2})		Weed dry weight (kg ha^{-2})	
	2016	2017	2016	2017	2016	2017
WI_{14}	1.7 h	2.3 g	26.7 c	27.0 c	1989.5 c	2124.5 a
WI_{28}	2.2 g	3.2 f	38.0 b	40.0 b	2304.4 b	3155.0 b
WI_{42}	3.1 f	4.4 e	50.5 a	56.9 a	3033.5 a	3847.6 a
WI_{56}	6.2 d	6.1 c	55.6 a	57.8 a	3134.4 a	3816.1 a
WI_{har}	8.9 a	8.5 a	56.5 a	58.6 a	3410.3 a	3813.2 a
WF_{14}	7.8 b	7.5 b	45.2 a	59.4 a	3083.1 a	3428.3 a
WF_{28}	6.9 c	6.4 c	39.8 b	41.8 b	2403.8 b	2703.2 b
WF_{42}	6.0 d	5.0 d	24.5 c	28.1 c	1924.4 c	2178.0 c
WF_{56}	5.1 e	4.0 ef	25.1 c	30.5 c	1645.1 c	2052.9 c
WF_{har}	1.6 h	2.2 g	23.3 c	26.3 c	1586.4 c	2102.6 c
SE± ($p<0.05$)	0.31	0.80	12.88	12.25	468.5	580.4

WI_{14}- weed-infested until 14 Days after sowing (DAS), WI_{28}- weed-infested until 28 DAS, WI_{42}- weed-infested until 42 DAS, WI_{56}- weed-infested until 56 DAS, WI_{har}- weed-infested from sowing till harvest, WF_{14}- weed-free until 14 DAS, WF_{28}- weed-free until 28 DAS, WF_{42}- weed-free until 42 DAS, WF_{56}- weed-free until 56 DAS, WF_{har}- weed-free from sowing till harvest. Means followed by the same letters are not significantly different ($p\leq0.05$; Turkey's HSD test).

Table 4 - Soybean growth response to different period of weed interference in 2016 and 2017

Weed interference(1)	Crop vigor score		Canopy height (cm)		Number of branches		Number of leaves		Leaf area index		Dry weight (g $plant^{-1}$)		Crop growth rate	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
WI_{14}	6.4 a	7.4 a	96.5 a	95.0 a	8.0 a	7.6 a	32.0 a	27.6 a	2.8 a	2.7 a	36.4 a	36.2 a	0.5 a	0.4 a
WI_{28}	5.9 b	6.2 c	90.0 b	89.5 b	7.1 b	7.2 b	23.4 b	20.0 b	2.4 b	2.1 c	33.6 b	33.3 b	0.4 b	0.3 b
WI_{42}	5.5 c	5.4 d	81.9 c	80.9 c	6.5 c	6.9 c	18.7 c	20.3 b	2.1 c	1.9 d	30.8 c	30.1 c	0.3 c	0.2 c
WI_{56}	5.4 c	5.8 d	80.6 c	80.4 c	6.5 c	6.7 c	18.1 c	16.2 c	2.1 c	1.9 d	30.1 c	30.6 c	0.3 c	0.2 c
WI_{har}	5.2 c	5.6 d	80.0 c	77.2 c	6.4 c	6.9 c	19.9 c	16.1 c	2.0 c	1.9 d	29.5 c	28.8 c	0.3 c	0.2 c
WF_{14}	5.3 c	5.6 d	82.9 c	80.0 c	6.5 c	6.6 c	19.3 c	17.8 c	2.0 2	2.0 c	29.9 c	29.5 c	0.3 c	0.2 c
WF_{28}	5.8 d	7.0 b	90.8 b	88.0 b	7.1 b	7.1 b	25.7 b	21.3 b	2.5 b	2.4 b	32.4 b	33.2 b	0.4 b	0.3 b
WF_{42}	6.5 a	7.4 a	100.7 a	91.0 a	7.7 a	7.5 a	31.2 a	28.8 a	2.8 a	2.7 a	34.9 a	34.9 a	0.5 a	0.4 a
WF_{56}	6.2 a	7.8 a	101.6 a	94.0 a	7.9 a	7.5 a	34.6 a	28.3 a	2.9 a	2.8 a	36.4 a	36.6 a	0.5 a	0.4 a
WF_{har}	6.6 a	7.6 a	102.3 a	100.0 a	8.0 a	7.5 a	34.6 a	30.2 a	3.0 a	2.9 a	36.4 a	36.0 a	0.5 a	0.4 a
SE±($p<0.05$)	0.32	0.43	5.82	5.74	0.43	0.37	4.3	3.6	0.23	0.18	2.2	2.6	0.06	0.06

WI_{14}- weed-infested until 14 Days after sowing (DAS), WI_{28}- weed-infested until 28 DAS, WI_{42}- weed-infested until 42 DAS, WI_{56}- weed-infested until 56 DAS, WI_{har}- weed-infested from sowing till harvest, WF_{14}- weed-free until 14 DAS, WF_{28}- weed-free until 28 DAS, WF_{42}- weed-free until 42 DAS, WF_{56}- weed-free until 56 DAS, WF_{har}- weed-free from sowing till harvest. Means followed by the same letters are not significantly different ($p\leq0.05$; Turkey's HSD test).

Table 5 - Yield and yield components of soybean in response to different period of weed interference

Weed interference(1)	Number of pods $plant^{-1}$		Number of seed $plant^{-1}$		Number of seeds pod^{-1}		Pod weight (g $plant^{-1}$)		100 seed weight (g)		Seed weight (g $plant^{-1}$)		Seed yield (kg ha^{-1})	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
WI_{14}	108.0 a	96.6 a	249.8 a	193.8 a	2.53	2.31	27.5 a	27.2 a	10.0 a	9.3 a	25.5 a	20.1 a	2147.2 a	1961.2 a
WI_{28}	93.7 b	81.8 b	224.8 b	173.8 b	2.51	2.33	24.6 b	23.0 b	9.0 b	9.1 b	20.7 b	17.9 b	1906.9 b	1555.9 b
WI_{42}	79.7 c	71.0 c	199.7 c	153.8 c	2.49	2.34	20.6 c	19.8 c	8.2 c	8.3 c	17.0 c	14.7 c	1066.7 d	1050.7 c
WI_{56}	75.5 c	70.3 c	184.7 c	153.8 c	2.46	2.35	18.6 c	18.5 c	8.7 c	8.6 c	17.2 c	14.6 c	1026.4 d	1045.4 c
WI_{har}	77.3 c	68.7 c	184.5 c	143.8 c	2.42	2.38	18.7 c	17.1 c	8.2 c	8.4 c	16.8 c	13.2 c	945.4 d	914.3 c
WF_{14}	75.8 c	70.1 c	189.5 c	149.5 c	2.72	2.66	19.3 c	19.9 c	8.3 c	8.6 c	16.3 c	13.2 c	1029.1 d	1054.5 c
WF_{28}	87.4 b	78.2 b	209.3 b	183.3 b	2.74	2.58	23.1 b	24.4 b	9.4 b	9.4 b	20.8 b	17.3 b	1588.7 c	1460.5 b
WF_{42}	106.9 a	96.2 a	257.1 a	197.1 a	2.76	2.49	27.9 a	28.0 a	10.0 a	9.1 a	24.4 a	20.4 a	2148.3 a	1966.5 a
WF_{56}	110.4 a	94.3 a	260.9 a	199.9 a	2.78	2.40	28.7 a	27.5 a	10.0 a	9.2 a	25.9 a	20.4 a	2107.9 a	1972.5 a
WF_{har}	110.5 a	100.4 a	264.5 a	198.5 a	2.82	2.23	30.3 a	28.6 a	10.0 a	9.3 a	26.0 a	21.6 a	2127.1 a	1984.5 a
SE ±($p<0.05$)	6.7	7.0	17.1	11.8	4.4^{ns}	4.9^{ns}	3.1	2.6	0.5	0.3	2.8	2.4	159.2	174.8

WI_{14}- weed-infested until 14 Days after sowing (DAS), WI_{28}- weed-infested until 28 DAS, WI_{42}- weed-infested until 42 DAS, WI_{56}- weed-infested until 56 DAS, WI_{har}- weed-infested from sowing till harvest, WF_{14}- weed-free until 14 DAS, WF_{28}- weed-free until 28 DAS, WF_{42}- weed-free until 42 DAS, WF_{56}- weed-free until 56 DAS, WF_{har}- weed-free from sowing till harvest. Means followed by the same letters are not significantly different ($p\leq0.05$; Turkey's HSD test). ^{ns} not significant.

probably because there was little growth from the perennial weeds at this stage. Only grass weed seedlings and few annual broad-leaved weeds were present at this initial stage of crop growth, and these were small and physiologically immature to offer significant competition to the crop seedlings. This result is similar to those reported by Adigun et al. (2014) and Osipitan et al. (2016) in which weed infestation for the first 21 DAS had no effect on crop growth and yield.

Increasing periods of weed interference in the early stage of crop growth; from 14 to 28 and 28 to 42 DAS (WI_{14} - WI_{28} - WI_{42}) resulted in significant reduction in all the growth and yield parameters in both years (Tables 4 and 5). Crop vigor score was reduced by 11 - 22% as period of weed interference increased to 28 DAS (WI_{28}) and by 16 - 41% as period of weed interference increased to 42 DAS (WI_{42}) compared to crops kept weed-free till harvest in both years (Table 4). Similarly, number of branches was reduced by 4 - 11% with increasing period of weed interference until 28 DAS (WI_{28}) and by 9 - 20% until 42 DAS (WI_{42}) compared to crops kept weed-free till harvest in both years (Table 4). Weed interference between 14 and 42 DAS (WI_{14} - WI_{28} - WI_{42}) reduced number of leaves by 32 - 46%, leaf area index by 26 - 35%, dry weight by 13 - 15%, crop growth rate by 7 - 22% compared to crops kept weed-free till harvest in both years (Table 4). Increasing period of weed interference to 42 DAS (WI_{42}) decreased number of pods per plant by 28 - 29%, number of seed per plant by 23 - 24%, pod weight by 31 - 32%, seed weight by 32 - 34% and 100 seed weight by 10 - 18%, but had no significant effect on number of seeds per pod (Table 5).

The weed-free treatment (WF_{har}) gave a yield of 1,984 - 2,084 kg ha^{-1} compared to 914 - 945 kg ha^{-1} without weed control (WI_{har}); a 53 - 56% reduction. Increasing period of weed interference in the early stage of crop growth (WI_{14} - WI_{28} - WI_{42}) resulted in a steady reduction in grain yield; a 47 - 50% reduction compared to the weed-free treatment (WF_{har}). Yield losses equivalent of 32 - 37 kg ha^{-1} of grain resulted for each day that weed control was delayed between 14 and 42 DAS in both years (Table 5). Rapid weed growth occurred between 14 and 42 DAS. Hence, the significant reduction in growth and yield observed during this period may be due to the increase in weed competition for growth resources. Previous finding of Khaliq et al. (2012) have shown that there is limited use of resource for crop growth and productivity due to increase in weed competition.

Weed interference after 42 DAS did not reduce the growth and yield of soybean significantly as plots with weed interference for 42 DAS and beyond (WI_{42}, WI_{56} and WI_{har}) had similar values for all the growth and yield parameters in both years (Tables 4 and 5). On the other hand, weed control after 42 DAS did not appear to be critical as plots kept weed-free for 42 DAS and beyond (WF_{42}, WF_{56} and WF_{har}) also recorded similar values for all the growth and yield parameters in both years (Tables 4 and 5). Weed density and biomass in plots where weeds were allowed to grow for 42 DAS did not differ significantly from those where weeds were allowed to grow till harvest. Hence, their subsequent removal was therefore not expected to alleviate crop growth and yield. While a significant increase in soybean growth and yield was observed for soybean kept weed-free for 42 DAS (WF_{42}) compared to 14 and 28 DAS (WF_{14} and WF_{28}), no growth and yield benefit resulted from weed control after 42 DAS. This may have been due to the canopy closure of soybean which could have limited the penetration of light to the weeds emerging below the leaves, thereby reducing late-season weed competition (Steckel and Sprague, 2004).

4 Conclusions

This study showed that the period of most rapid weed growth and highest yield reduction due to weed interference was between 14 and 42 DAS. Hence, soybean should be maintained weed-free between 14 and 42 DAS for maximum grain yield. There is no growth and yield benefit from weed control before 14 DAS and after 42 DAS.

5 Contributions

Data collection, formal analysis, methodology, resources, writing, reviewing and editing of this manuscript was done solely by DOS.

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