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Row Spacing Determines Critical Period of Weed Control in Crop: Cowpea (*Vigna unguiculata*) as a Case Study

Omobolanle Adewale Osipitan[1*], Joseph Aremu Adigun[1], Rauf Olabisi Kolawole[1]

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ABSTRACT

To further understand the importance of row spacing as an agronomic practice, a study was conducted to evaluate how levels of row spacing determines the critical period of weed control (CPWC) in cowpea (*Vigna unguiculata*). The experiment was laid out as a split-plot design with eight periods of weed interference as the main plots and three row spacing (60, 75 90 cm) as the subplots with three replications of each treatment combination. Period of weed interference consisted of weed removal for 14, 35, 54, and 77 days after emergence (DAE), and weed infestation for 14, 35, 54, and 77 DAE. Results indicated that the mean yield of cowpea was higher at narrow spacing (60 cm) than at wide spacing (90 cm) under season-long weed infestation plots but no difference in yield was found among the row spacing in the season-long weed removal plots. There was no difference in the beginning of the CPWC among the row spacing. However, 90 cm row spacing requires longer period of weed removal to avoid unacceptable yield loss when compared to 60 cm row spacing. The end of the CPWC coincides with the period of canopy closure by the crop. This finding suggests that it took the crop longer time to close canopy at wide row spacing (90 cm) compare to reduced row spacing. The differences in the duration of weed control intervention in crop row spacing suggest the importance of integrating decisions regarding row spacing and period of weed control in weed management strategies.

INTRODUCTION

Cowpea (*Vigna unguiculata*) is one of the most important grain legume in the tropics regions of Asia and Africa (FAO 2006). Weeds constitute a major constraint to arable crop production and losses cause by weeds alone in cowpea production can range from 25% to 70% depending on the cultivar and environment (Adigun et al. 2014). In order to develop efficient weed control strategy and provide a logical basis for the development of an integrated weed management system, information on the critical period of weed control (CPWC) is essential (Hall et al. 1992). CPWC is the period during the life cycle of a crop when it must be kept weed-free in order to prevent a specific level of yield loss (Martin et al. 2001). Theoretically, weed control before and after the CPWC does not significantly contribute to the conservation of crop yield Potential (Knezevic and Datta 2015). The functional approach to determining CPWC consist of two components, weed infestation and weed removal curves which determines beginning and end of CPWC respectively (Knezevic and Datta 2015). In this approach, the Acceptable Yield Loss (AYL) a farmer can risk based on agronomic and economic considerations is critical in determining the duration of the CPWC. As reviewed by Knezevic and Datta (2015) the AYL is usually between 2.5 and 10%. The general goal of CPWC studies is to provide information to farmers on most appropriate timing and periodicity for weed control in order to ensure cost effectiveness, reduce herbicide pressure, prevent or delay evolution of herbicide resistance, and reduce environmental pollution and degradation. The duration of CPWC vary depending on several factors, including crop and weed characteristics, environmental variables, and cropping practices. Cropping practices include but not limited to crop planting density and row spacing (Hall et al. 1992, Teasdale 1995, Knezevic et al. 2003). Reducing crop row spacing and

[1] Department of Plant Physiology and Crop Production College of Plant Science and Crop Production Federal University of Agriculture, P.M.B 2240 Abeokuta-Nigeria.
*Email: waleos08@yahoo.com

increasing planting density have shown to improve the tolerance and competitiveness of crop to weed (Mulugeta and Boerboom 2000, Knezevic et al. 2003, Osipitan et al. 2013). Osipitan et al. (2013) indicated that cowpea planted in 60 cm rows was more tolerance and suppressive against weeds than those in 90 cm wide rows. The influence of row spacing on the competitiveness of crop against most weeds may be attributed to the fact that narrow row crops close canopy earlier than wide rows and therefore influence light penetration to the soil surface, modifying weed emergence patterns and growth (Knezevic et al. 2003, Fedoruk et al. 2011). Despite the potential of row spacing in influencing crop-weed relationship and CPWC, there is no published information on how row spacing may determine the beginning and duration of CPWC in cowpea. Determining effects of row spacing on the CPWC will further explain the importance of row spacing in integrated weed management strategies. The objective of this study is to determine the impact of three row spacing on critical period of weed control in cowpea.

MATERIALS AND METHODS

Experimental site, design and procedure

Trials were conducted during the early and late wet season in 2009 at Teaching and Research Farm of the University of Agriculture, Abeokuta (7^o 20^1N, 3^o 23^1E), in the Forest-Savanna transition zone of South Western Nigeria. The location is characterized by a bimodal rainfall pattern with peaks usually in July and September and short dry spell in August with annual mean of about 1300 mm and a mean temperature of about 27°C. Soil samples were taken randomly from a depth of 0-30 cm on the experimental site after land preparation but before fertilizer application to analyze its physico-chemical properties. Soil physico-chemical properties are shown in Table 1. The experimental sites were cultivated by ploughing and disk-harrowing at two weeks interval prior to seeding the crop. Inorganic fertilizers were broadcast at the rate of 45 kg ha^{-1} each of available phosphate (P_2O_5) and soluble potash (K_2O) before harrowing. Seeding of crop for early trial was done in last week of March, 2009 and that of late trial was done in first week of August, 2009. Seeds of crop were sown at the rate of two to three seeds per hole and later thinned to two per stand. Insecticide (cypermethrin) and fungicide (carbendazim) were applied at the onset of flowering and subsequently fortnightly until pod maturity to protect the plants against insect and disease damage.

The experiment was laid out as a split-plot design with eight periods of weed interference as the main plots and three row spacing (60, 75 and 90 cm) as the subplots with three replications of each treatment combination. The period of weed interference consisted of weed removal for 14, 35, 54, and 77 days after emergence (DAE), and weed infestation for 14, 35, 54, and 77 DAE. Weed removal and weed infestation for 77 DAE were considered as season-long weed interference treatments. Weeds control was achieved by hand-hoeing. A naturally occurring population of weed species was utilized to obtain appropriate period of weed interference. The weed species with count of at least 5 plants m^{-2} at a period of observation were: (1) Broadleaves; *Acanthospermum hispidium, Amaranthus spinousus, Boerhavia coccinea, Boerhavia diffusa, Chromolanae odorata, Euphorbia heterophylla, Hyptis lanceolate, Senna hirsute, Talinum triangulare, Tithonia diversifolia,* and *Tridax procumbens* (2) Grasses; *Branchiaria lata, Cynodon dactylon, cyperus esculentus, Imperata cylinrica* and *Panicum maximum.* Each subplot was 3 m wide and 4.5 m long but the marked observation area was 1.5 m away from each plot edge. Alleyway of 2 m was created between replicates and 1.5 m between subplots. Weed density, species composition and biomass were assessed in all plots before every weed removal activity. While for the season-long weed interference treatments, weed were removed at 14, 35, 54, and 77 DAE to capture weed growth pattern. Weed sampling was done using a quadrat of 0.5 m by 0.5 m within the marked observation area.

Grain yield of cowpea was harvested after physiological maturity within marked observation area from each plot. Harvesting was carried out in July 28 for the early season trial and November 9, for the late season trial.

Statistical analysis

ANOVA using mixed model procedures in SAS 9.4 software (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414) was initially performed to test the significance of the treatments (period of weed interference, row spacing and their interaction) on weed biomass and cowpea yield. Trial (early or late cropping season), and replicates

Table 1. Physico-Chemical characteristics of experimental soil in early late wet season of 2009

Soil properties (0-15cm depth)	Early trial	Late trial
Physical Properties		
Sand (%)	89.8	88.0
Silt (%)	1.4	2.30
Clay (%)	8.8	10.10
Textural class	Loamy sand	Loamy sand
Chemical Properties		
pH (H_2O) (1:2)	6.8	7.11
Organic carbon (%)	5.23	4.88
Total nitrogen (%)	0.10	0.07
Available phosphorus (PPM)	20.10	20.40
Potassium (mg/kg)	11.00	7.2
$Na^{=1}$	7.5	7.5

Table 2. The effect of period of weed interference on weed biomass. Values were compared using Turkey's honestly significant different, α = 5%

Period of weed interference	Weed biomass (t ha^{-1})					
	Early trial			Late trial		
	Spacing (cm)			Spacing (cm)		
Weed removal period (DAE)	60	75	90	60	75	90
14	5.24 a	5.30 a	5.35 a	6.20 a	6.43 a	6.53a
35	4.50 b	4.64 b	4.78 b	3.80 b	4.20 b	4.30 b
54	4.31 b	4.52 b	4.67 c	3.70 b	4.00 b	4.30 c
77	4.35 b	4.54 b	5.00 c	3.90 b	4.00 b	4.00 c
Weed infestation period (DAE)						
14	4.70 d	4.49 c	4.61 c	3.70 c	3.80 c	3.80 d
35	5.07 c	5.38 b	5.66 b	6.30 b	6.40 b	6.50 c
54	10.50 b	11.37 a	12.00a	14.43 a	14.70 a	15.00 b
77	11.07 a	11.09 a	11.95a	14.27 a	14.93 a	15.50 a

Values with the same letters within the same column are not significantly different.

within a trial were considered as random effects, while period of weed interference and row spacing were considered as fixed effects.

There was a significant interaction between trial and treatments for weed biomass and cowpea yield; therefore, each trial was analyzed separately. ANOVA was then conducted for weed biomass and cowpea yield for each trial, with replicates included as a random effect and the treatments as fixed effects. Tukey honestly significant differences (α= 5%) was used to compare means. Cowpea yield was regressed against the DAE for weed removal period and weed infestation period using three-parameter log-logistic function as described by Knezevic et al. (2007) for each row spacing using R software (R Development Core Team 2015).

$$Y= D/1 + \exp [B(\log X - \log E)] \quad [1]$$

where Y is the cowpea yield, D is the maximum yield, X is days after crop emergence (DAE) as the explanatory variable. E (ED_{50}), is the DAE to attaining 50% of maximum yield, B is the relative slope around the ED_{50}. To estimate the CPWC, the procedure described by Knezevic and Datta (2015) was used. The CPWC was estimated using the two components of period of weed interference; weed infestation period (determines the beginning of the CPWC) and weed removal period (determines the end or duration of the CPWC). Acceptable yield loss (AYL) is the basis on which the CPWC is determined, and AYL of 5 and 10% were used to represent the yield loss risk a farmer may accept. R software (R Development Core Team 2015) have in built commands that allows the adjustment of the ED, hence, ED_5 and ED_{95} or ED_{10} and ED_{90} were used based on the AYL under consideration. For AYL of 5%, the beginning of the CPWC using weed infestation period curve was estimated with ED_5, while the end of the CPWC using weed removal period curve was estimated with ED_{95}. For AYL of 10%, the beginning of the CPWC using weed infestation period curve was estimated with ED_{10}, while the end of the CPWC using weed removal period curve was estimated with ED_{90}. SI (selectivity index) was used to compare the relative differences of the beginning and the end of CPWC among the row spacings for each trial (Knezevic and Datta 2015).

Table 3. Parameter estimates (standard error in parenthesis) for the three-parameter log-logistic function characterizing the cowpea yield response to the weed removal period (Equation 1).

Trial	Row spacing (cm)	Parameter estimates (±SE) B	D (kg ha^{-1})	E (days)
Early	60	-7.21 (3.43)	717 (15)	12 (8)
	75	-1.25 (3.62)	739 (45)	14 (23)
	90	-1.43 (6.51)	493 (14)	16 (47)
Late	60	-8.71 (8.20)	750 (10)	17 (10)
	75	-1.20 (3.44)	723 (21)	19 (10)
	90	-1.37 (5.32)	509 (31)	24 (2)

RESULTS AND DISCUSSION

Based on analysis of variance (ANOVA),

Table 4. Parameter estimates (standard error in parenthesis) for the three-parameter log-logistic function characterizing the cowpea yield response to the weed infestation period (Equation 1).

Trial	Row spacing (cm)	Parameter estimates (±SE) B	D (kg ha^{-1})	E (days)
Early	60	1.25 (1.59)	600 (30)	64 (49)
	75	0.95 (2.26)	584 (37)	40 (157)
	90	1.59 (2.29)	446 (41)	37 (49)
Late	60	1.17 (2.18)	911 (21)	39 (9)
	75	0.81 (2.91)	862 (34)	96 (58)
	90	1.40 (3.13)	795 (20)	22 (95)

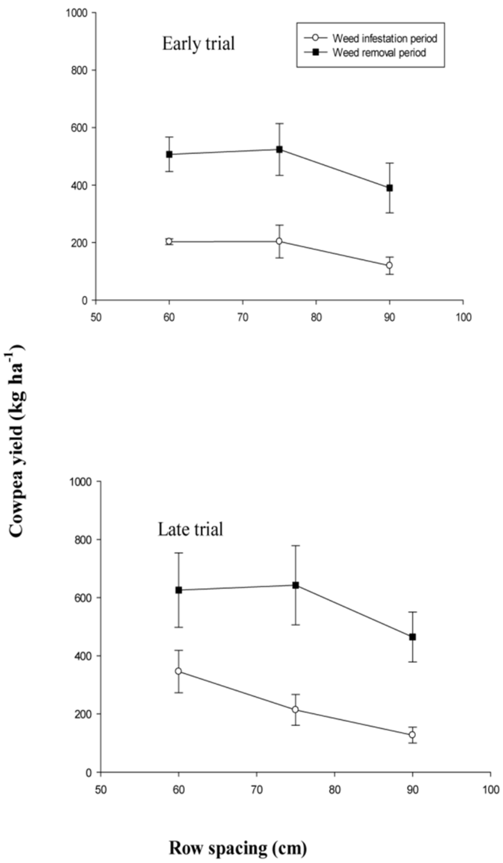

Figure 1. Mean cowpea yield response to three row spacing in the season-long weed infestation and season-long weed removal plots for early and late trials.

both period of weed interference and row spacing had significant effect on weed biomass and cowpea yield. Irrespective of row spacing, early weed control for only first 14 days after crop emergence (DAE) without any subsequent weed removal resulted to significant accumulation of weed biomass during the crop growing season (Table 2). While weed biomass accumulation of plots with weed control for the first 35 DAE and beyond were not different for row spacing of 60 and 75 cm. However, at 90 cm row spacing, weed control up to about 54 DAE is required to ensure negligible subsequent weed growth during the crop growing season. Irrespective of row spacing, delayed weed removal (weed infestation period) significantly increased weed growth during the cropping season (Table 2).

The p-values (α= 5%) of the three-parameter log-logistic models did not indicate any lack of fit for the yield response data. The rate of yield response to period of weed interference (B), and the DAE to attaining 50% of maximum yield (E) were not different among crop row spacings, while the maximum grain yield (D) obtained from these row spacings were different (Tables 3 and 4).

Cowpea yields varied between early and late wet season trials (Figure 1). The differences in yield of trials may be attributed to differences in the environmental conditions during the study. As expected, the yield of the late wet season was higher than the early wet season because the temperature towards the end of the late season, provided warm condition that better promotes cowpea flowering, pod filling and seed dryness. Yields from season-long weed-removal plots ranged from 458 to 650 kg ha^{-1}, compared with much lower yields of 190 to 260 kg ha^{-1}in season-

Table 5. Estimates (standard error in parenthesis) for the beginning and end of the critical period of weed control (CPWC) in cowpea on the basis of days after emergence using three-parameter log-logistic model (Equation 1).

Trials	Acceptable Yield Loss (AYL)	Spacing	Beginning of CPWC (weed-infestation curves)	End of CPWC (weed-removal curves)
	Percentage	cm	Days after emergence (± SE)	Days after emergence (± SE)
Early		60	6 (2.1) a	43 (7.9) b
	5	75	5 (2.8) a	59 (10.9) ab
		90	2 (4.8) a	85 (6.9) a
		60	11 (1.7) a	35 (9.9) b
	10	75	6 (4.4) a	47 (7.2) b
		90	9 (7.8) a	72 (6.7) a
Late		60	3 (0.9) a	46 (10.3) b
	5	75	3 (1.1) a	60 (13.7) ab
		90	1 (2.2) a	90 (21.3) a
		60	6 (2.1) a	39 (13.9) b
	10	75	5 (2.9) a	47 (21.3) ab
		90	6 (1.8) a	71 (12.7) a

Values with the same letters within the same column are not significantly different for each AYL. Comparison was based on selectivity index (SI) as described by Knezevic and Datta (2015).

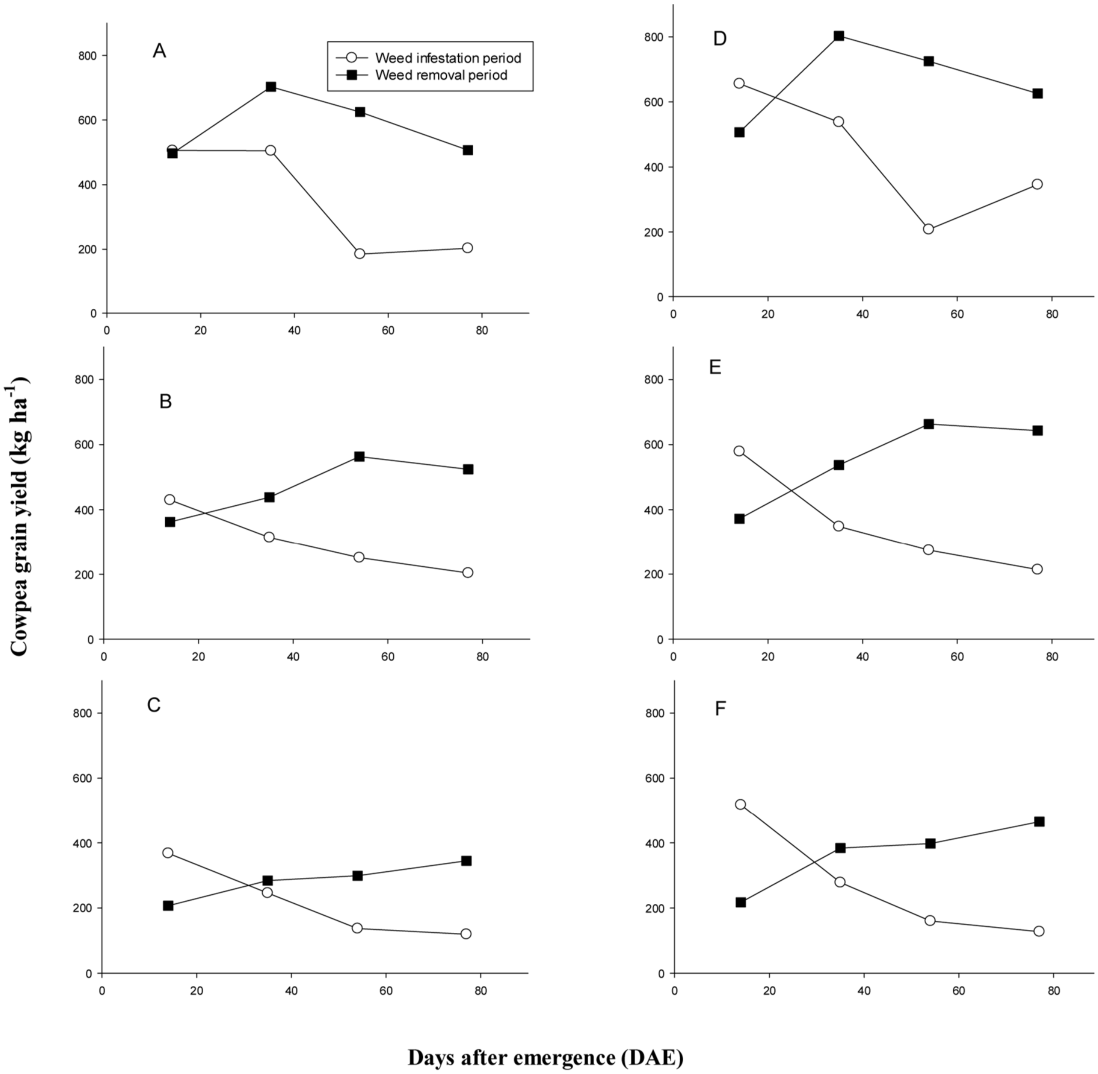

Figure 2A, B and C are for 60, 75 and 90 cm row spacing respectively for the early season trial while Figure 2D, E and F are for 60, 75 and 90 cm row spacing respectively for the late season trial

long weedy plots (Figure 1). In both trials, the mean yield of cowpea was higher at narrow spacing (60 cm) than at wide spacing (90 cm) under season-long weed infestation plots but no difference in yield was found among the row spacing in the season-long weed removal plots (Figure 1). The difference in cowpea yield under season-long weed infestation and removal suggests that differences between row spacing on yield can be magnified by increasing competition from weeds. In other words, importance of row spacing can be more valued when weed interference impacts yield (Knezevic et al. 2003).

Critical period of weed control

The beginning and end of the critical period of weed control (CPWC) were determined by weed infestation period curves and weed removal period curves respectively (Equation 1; Table 5; Figure 2). In general, the early wet season trial had shorter CPWC than late wet season trial. This may be due to less weed growth at the former than the later (Table 2). The higher the acceptable yield loss (AYL), the shorter the duration of CPWC (Table 5). The beginning of the CPWC was consistently similar for all row spacing (60, 75 and 90 cm) while the duration of the CPWC varied among the row spacing. At AYL of 5 and 10% tested, reduced spacing (60 cm) consistently resulted to shorter duration of CPWC compared to wider (90 cm) row spacing (Table 5; Figure 2). For instance, in the second trial, at 5% AYL, 60 cm spacing had CPWC of 3 to 46 days after emergence (DAE); 75 cm spacing had CPWC of 3 to 60 DAE; while 90 cm spacing had CPWC of 1 to 90 DAE (Table 5; Figure 2D, E and F). The beginning and end of the CPWC depend on the level of acceptable yield loss (AYL) used to predict its beginning and end (Knezevic and Datta 2015). In this study the 10%

AYL consistently had shorter duration of CPWC compared to 5% (Table 5).

These results suggest that early weed control is important in cowpea irrespective of the row spacing. Similarly, previous studies on lentils (Singh et al. 1996, Fedoruk et al. 2011), soybean (Knezevic et al. 2003), spring canola (Martin et al. 2001), corn (Hall et al. 1992) and cowpea (Adigun et al. 2014) suggested that CPWC commenced few days after crop emergence. However, duration of weed control substantially depends on row spacing. The resultant longer duration of CPWC in wider row spacing may be attributed to: (1) availability of wider biological space for weed growth with consequent reduction in availability of below and above ground resources; (2) and relatively longer time required for cowpea to achieve canopy cover necessary to suppress weed growth. These give weeds biological advantage over cowpea, as a result, more time is required to remove weeds between the row until cowpea can independently suppress weed through canopy cover that helps to reduce the quality and quantity of light available for the new cohorts of weeds. These results support previous studies (Nanju 1978, Chauhan and Johnson 2011) that narrow row spacing can help increase crop competitive advantage over weed, thereby reducing weed management time and effort.

CONCLUSION

This study confirmed that the crop row spacing significantly influenced crop-weed interference and the duration of weed control intervention in crop. The level of competitiveness of the crop with the weeds determines the duration of the CPWC and reducing crop row spacing helps to reduce the biological space for weed as well as increase the competitive advantage of crop through early canopy cover. The beginning of the CPWC is similar among the row spacing tested. This may be because the beginning of the CPWC is not a related to the crop's competitive ability but instead to the onset of early weed growth (Fedoruk et al. 2011). The differences in the duration of weed control intervention in crop row spacing documented in this study highlight the importance of integrating decisions regarding crop row spacing and the timing of weed control in weed management strategies. The implication of this study is that planting cowpea in wider rows (90 cm) would require weed control method that would provide longer duration of weed removal compare to planting at reduced spacing (60 cm).

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