Original Research Article

Efficacy and economics of integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench)

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Abstract

Weed management is one of the most important and expensive steps in okra production. Field experiments were therefore conducted in the early and late wet seasons of 2015 to evaluate the effectiveness and profitability of weed management using hoe weeding, herbicides or their combination in okra production. Propaben or butachlor at 2.0 kg a.i. (active ingredient) ha^{-1} followed by (fb) supplementary hoe weeding (shw) at 6 weeks after sowing (WAS) significantly ($P < 0.05$) reduced weed density and biomass with subsequent increase in okra fruit yield similar to three hoe weedings and better than two hoe weedings or either herbicide applied alone in both early and late wet seasons. Although three hoe weedings provided the highest okra fruit yield (3590 and 4102 kg ha^{-1}) and total revenue ($991.7 and $1699.7 ha^{-1}), the gross margin ($186.4 and $931.6 ha^{-1}) and cost-benefit ratio (0.2 and 1.2) obtained were lower than those obtained with herbicide treatments. Highest gross margin ($470.8 and $1224.9 ha^{-1}) and cost-benefit ratio (1.2 and 3.0) in the early and late wet seasons, respectively, were achieved with propaben at 2.0 kg a.i ha^{-1} fb shw at 6 WAS. The results of this study suggest that integrated weed management with propaben followed by supplementary hoe weeding will improve weed control, productivity and profitability of okra. Multiple hoe weeding, however, did not guarantee highest profit but rather increased the cost of production.

Keywords: herbicides; butachlor; propaben; fruit yield; hoe weeding; weed interference; revenue; cost-benefit ratio

INTRODUCTION

The demand for okra (*Abelmoschus esculentus* L. Moench) is increasing in Africa due to its increasing importance in the farming systems and daily diet of smallholder farmers (Olasantan and Bello, 2003). Okra is grown almost everywhere in the tropical, subtropical and warm temperate regions as a main crop or in mixture with staple food crops such as yam, maize, cassava and cowpea, or with various vegetable crops (Salau and Makinde, 2016). It is one of the most important fruit vegetable crop and a source of calorie (4550 Kcal/kg) for human consumption (Babatunde et al. 2007). Okra is also a good source of vitamins A, B and C, and iron, calcium, magnesium, phosphorus and zinc (Asian Vegetable Research Development Council, 1991).

Nigeria is the second largest producer of okra in the world after India with an average production of 2.7 million tonnes from about 1.4 million hectares (FAOSTAT, 2018). Despite the nutritive value and increased importance of okra, yields obtained from farmer's field in Nigeria are very low. Average okra yield in Nigeria is about 1.3 t ha^{-1} which is far below the world average of 7.5 t ha^{-1} (Navdeep and Daljeet, 2016). Among the factors attributed for the low yield of okra in Nigeria, weed infestation is the most deleterious (Imoloame and Muinat, 2018). Weeds exert severe competition for nutrients, water and light resulting in 73–75% reduction in potential okra yield in different zones in Nigeria (Imoloame and Muinat, 2018).

Hoe weeding is the predominant weed control method used by farmers in Nigeria (Imoloame, 2014). However, the efficacy of hoe weeding is often compromised by the continued wet condition characteristic of the beginning of the rainy season. Hoe weeding under wet conditions often causes weed to re-root and re-establish, necessitating several rounds of weeding to keep the crop weed-free and avert yield losses. This is, however, tedious, inefficient, time consuming and associated with high labour demands (Datta et al., 2017; Adigun et al., 2018). In addition, labour for manual weeding is scarce and often too expensive for the average farmer to afford (Adigun et al., 2017). Herbicide use, on the other hand, although efficient, does not provide season-long

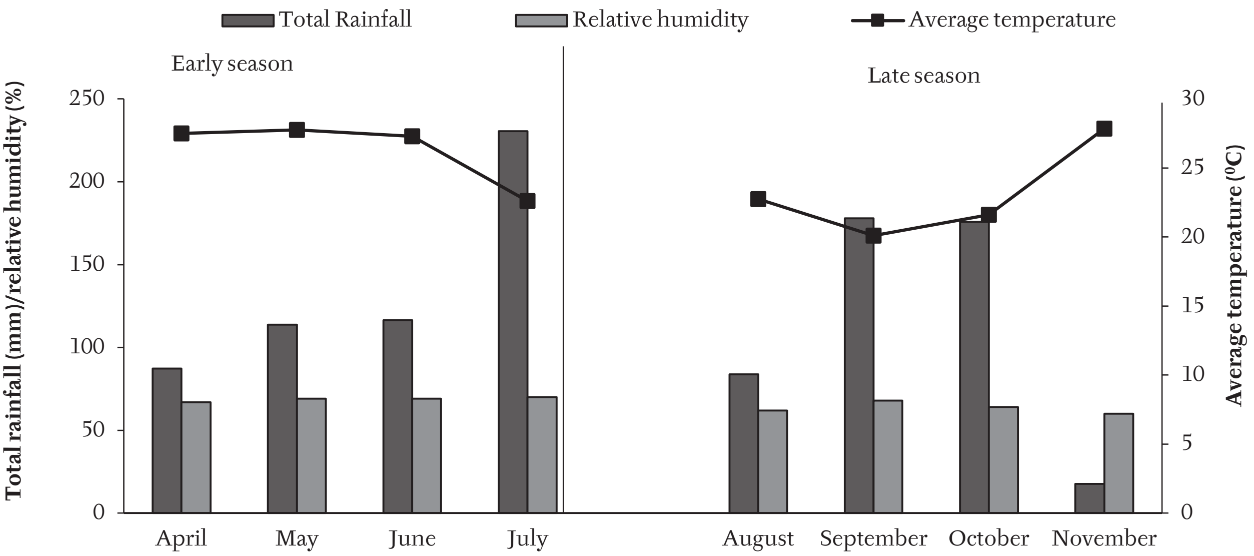

Figure 1. Monthly weather data during the period of crop growth in the early and late wet seasons of 2015.

weed control when used alone, and a single herbicide application may not control the entire weed spectrum (Chauhan et al., 2012). In addition, uncontrolled use of herbicides for weed control results in the increased number of herbicide-resistant weeds and environmental contaminations (Labrada, 2002). Hence there is a need to combine these weed management components for broad spectrum weed control. Combination of reduced number of hoe weedings and/or herbicide applications within the context of integrated weed management could help to improve weed control efficiency, reduce the high cost associated with multiple hoe weeding or herbicide applications and increase okra yield. Although few studies (Imoloame, 2014; Adigun et al. 2017) have reported increased weed control efficiency and higher yields with integrated weed management, economic consideration, particularly profit is more important to farmers in driving the adoption of agricultural innovation (Pannell et al. 2006). Practice with the best yield may not necessarily translate to the best economic benefit to farmers. There is inadequate information for smallholder farmers about weed control methods that would contribute to improved yield and provide trade-off in economic implications in okra production. We hypothesised that the integration of hoe weeding and herbicide application could help to improve weed control efficiency, reduce the high cost associated with multiple hand weeding and increase the yield of okra. Hence, this study was conducted to evaluate the efficacy and economic performance of weed management methods using hoe weeding, herbicides and their combination in okra production.

MATERIALS AND METHODS

Site description

Field experiments were carried out at the Federal University of Agriculture, Abeokuta, Nigeria (70 15′ N, 30 23′ E 159 m above sea level) during the early (April–July) and late (August–November) wet seasons of 2015. Abeokuta is located in the forest savannah transition zone of South-Western Nigeria and characterised by bimodal pattern of rainfall with mean annual rainfall of 1000 mm. The site received a total rainfall of 548 and 451 mm throughout the period of crop growth in the early and late wet seasons, respectively (Figure 1). The mean monthly temperature ranged from a minimum of 14.7 °C and 15.8 °C to a maximum of 32.1 °C and 33.1 °C in the early and late wet seasons, respectively (Figure 1). The soils of the fields in both years had a sandy loamy texture, pH of 6.7 and 6.9; organic matter of 2.5 and 2.1% and nitrogen of 0.25 and 0.21% in the early and late wet seasons, respectively.

Treatment details

The experiments in both early and late wet seasons consisted of six weed management methods and a weedy check. All the treatments were arranged in a randomised complete block design with three replications. The gross and net plot sizes in both years were 4.5 m × 3.0 m and 3.0 m × 3.0 m, respectively. The weed management treatments included:

- Pre emergence application of propaben at 2.0 kg a.i. (active ingredient) ha^{-1};
- Pre-emergence application of propaben at 2.0 kg a.i. ha^{-1} followed by (fb) supplementary hoe weeding (shw) at 6 weeks after sowing (WAS);

Table 1. Relative abundance of common weed species at the experimental sites in the early and late wet seasons of 2015

Weed species	Plant family	Level of infestation	
		Early	Late
Broad leaf weeds			
Tridax procumbens (Linn).	*Asteraceae*	***	***
Euphorbia heterophylla (Linn).	*Euphorbiaceae*	***	***
Commelina benghalensis (Burn.)	*Commelinaceae*	***	**
Gomphrena celosioides (Mart.)	*Amaranthaceae*	***	**
Spigelia anthelmia (Linn).	*Loganiaceae*	***	***
Boerhavia diffusa (Linn).	*Nyctaginaceae*	***	**
Chromolaena odorata (L.) R.M. King and Robinson	*Asteraceae*	***	**
Grasses			
Digitaria horizontalis (Willd.)	*Poaceae*	***	**
Panicum maximum (Jacq.)	*Poaceae*	***	***
Axonopus compressus (Sw.) P. Beauv.	*Poaceae*	***	***
Eleusine indica (Gaertn.)	*Poaceae*	**	**
Rottboellia cochinchinensis (Lour.) Clayton	*Poaceae*	*	*
Cynodon dactylon (L) Gaertn.	*Poaceae*	***	***
Sedge			
Cyperus rotundus	*Cyperaceae*	**	**

*** – Highly infested (60–90%), ** Moderately infested (30–59%), * – Low infestation (1–29%)

- Pre-emergence application of butachlor at 2.0 kg a.i. ha^{-1};
- Pre-emergence application of butachlor at 2.0 kg a.i. ha^{-1}; fb shw at 6 WAS;
- Two hoe weedings at 3 and 6 WAS;
- Three hoe weedings at 3, 6 and 9 WAS;
- Weedy check.

Late maturing, high yielding okra cultivar (LD88) seeds that take 45–50 days to flower were sown manually at the onset of rain in the early and late wet seasons of 2015. Herbicide treatments were applied pre-emergence one day after sowing with knapsack sprayer (CP 15, Hozwlock-Excel, Cedex, France) and a spraying volume of 250 L ha^{-1} using deflector nozzle at a pressure of 2.1 kg cm^{-2}. Hoe weeding was done using West African hoe.

Weed observations

Data on weed density and weed dry matter (weed biomass) were collected at 12 WAS in both early and late seasons using a 50 cm × 50 cm quadrat placed randomly at three spots within each plot. Weeds sampled from the quadrat were counted and oven-dried at 70 °C for 72 hours, after which they were weighed and expressed in g m^{-2}.

Okra fruit yield

Green immature pods with tips that can be broken with a hand snap (not yet fibrous), were harvested every three days, from each plot, starting from 6 WAS in the early and late wet seasons. The cumulative pod weights in kg $plot^{-1}$ were then expressed in kg ha^{-1}.

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using GENSTAT discovery package to determine the level of significance of the treatments. Treatment means were separated using the least significant difference (LSD at $P \leq 0.05$).

Economic analysis

Gross margin was used to determine the profitability of weed control methods under different weed management methods in the early and late wet seasons. The gross margin is usually referred as a returns over variable cost and serves as a proxy measure of profitability (Maurice et al., 2005). The gross margin from production activities is the gross value of okra fruit yield outputs minus all the variable costs incurred during production. Revenue produced from each treatment was obtained by multiplying the yield by the steady mean market price (US 0.3 kg^{-1} and 0.4 in early and late wet seasons, respectively).

RESULTS

Weed species composition

A total of 14 weed species were encountered in both early and late wet seasons. The weed species comprised 7 broadleaf weeds, 6 grasses and 1 sedge (Table 1). The weed species represented 9 families among which the Poaceae family had the highest number of species (6). The weed species were generally more abundant in the early season compared with the late

Table 2. Effect of weed management methods on weed density, weed biomass and fruit yield of okra in early and late wet season of 2015

Weed management methods	Weed density (plants m^{-2})		Weed biomass (kg ha^{-1})		Fruit yield (kg ha^{-1})	
	Early	Late	Early	Late	Early	Late
Propaben	36.4	31.4	167.4	134.4	2655	3046
Propaben + shw at 6 WAS	27.5	24.6	130.2	92.6	3475	3965
Butachlor	35.2	25.2	174.5	128.5	2643	2904
Butachlor + shw at 6 WAS	22.7	22.3	121.3	89.1	3323	3831
Two hoe weedings	30.6	23.5	166.3	124.3	2579	3240
Three hoe weedings	24.0	22.4	123.5	91.4	3590	4102
Weedy check	61.9	46.7	633.4	449.2	1073	1213
LSD (5%)	5.2	3.3	9.4	10.9	309.4	370.0

WAS – weeks after sowing, shw – supplementary hoe weeding, LSD – least significant difference.

season. *Commelina benghalensis, Gomphrena celosioides, Boerhavia diffusa, Chromolaena odorata* and *Digitaria horizontalis* which had high infestation in the early season were found with moderate infestation in the late season (Table 1).

Effect of weed management methods on weed density and biomass in okra

All the weed management methods significantly reduced weed density and biomass compared to the weed check in both early and late wet seasons (Table 2). Propaben and butachlor each applied at 2.0 kg a.i ha^{-1} reduced weed density and biomass similar to two hoe weedings in both early and late wet seasons. Propaben and butachlor applied at 2.0 kg a.i ha^{-1} each followed by supplementary hoe weeding at 6 WAS reduced weed density and biomass similar to three hoe weedings and better than two hoe weedings or either herbicide applied alone in both early and late wet seasons. The lowest weed density (22.7 plants m^{-2} in the early and 22.3 plants m^{-2} in the late season) and weed biomass (121.3 kg ha^{-1} in the early and 89.1 kg ha^{-1} in the late season) were recorded in plots treated with butachlor at 2.0 kg a.i ha^{-1} followed by supplementary hoe weeding at 6 WAS.

Effect of weed management methods on fruit yield, cost of production and profitability of okra production

Regardless of weed management methods, okra fruit yield was generally higher in the late season compared to the early season (Table 2). All the weed control methods resulted in significantly higher okra fruit yield than the weedy check (Table 2). Propaben and butachlor each at 2.0 kg a.i ha^{-1} and two hoe weedings resulted in comparable okra fruit yield in both early and late wet seasons. However, application of propaben or butachlor at 2.0 kg a.i/ha each followed by supplementary hoe weeding at 6 WAS resulted in significantly higher okra fruit yield than two hoe weedings or either herbicides applied alone in both early and late wet seasons (Table 2). The highest okra fruit yield (3590 and 4102 kg ha^{-1} in the early and late wet seasons, respectively) was recorded in plots hoe weeded thrice at 3, 6 and 9 WAS. However, these were comparable with okra fruit yield (3475 and 3965 kg ha^{-1} in the early and late wet seasons, respectively) obtained with propaben followed by hoe weeding and okra fruit yield (3323 and 3831 kg ha^{-1} in the early and late wet seasons, respectively) obtained with butachlor followed by hoe weeding (Table 2). Unchecked weed growth throughout the period of okra growth resulted in 70.1 and 90.4% reduction in okra yield in the early and late wet seasons, respectively (Table 2).

All the weed management methods incurred higher cost of production than the untreated control weedy check (Table 3). Regardless of weed management methods, the total cost of production was generally higher in the early season than the late season (Table 3). Application of propaben and butachlor each applied alone at 2.0 kg a.i ha^{-1} or followed by supplementary hoe weeding at 6 WAS resulted in lower cost of production than two and three hoe weedings in both early and late wet seasons (Table 3). Of all the weed management methods, three hoe weedings incurred the highest cost of production ($853.3 and $768.1 ha^{-1} in early and late wet seasons, respectively) followed by two hoe weedings ($677.3 and $568.4 ha^{-1} in early and late wet seasons, respectively).

Regardless of weed management methods, there was a higher total revenue, gross margin and benefit-cost ratio in the late season compared to the early season (Table 4). The highest total revenue ($991.7 and $1699.7 in the early and late wet seasons, respectively) was recorded with three hoe weeding treatment. However, highest gross margin ($470.8 and $1224.9 in the early and late wet season, respectively) was recorded with propaben followed by hoe weeding (Table 4). Propaben or butachlor at 2.0 kg a.i ha^{-1} each followed by hoe weeding resulted in higher total revenue than two hoe weeding or either herbicide applied alone in both early and late wet seasons.

Table 3. Average variable cost (US dollar) of okra production in early and late wet seasons of 2015

Treatments	Early season						Late season					
	Seed/seed treatment	Land preparation	Planting	weed control	harvesting	Total	Seed/seed treatment	Land preparation	Planting	weed control	harvesting	Total
Propaben	29.0	77.1	92.9	40.4	90.9	330.3	29.0	55.2	92.9	40.4	90.9	308.4
Propaben + shw at 6 WAS	29.0	77.1	92.9	200.0	90.9	489.9	29.0	55.2	92.9	150.0	90.9	418.0
Butachlor	29.0	77.1	92.9	45.0	90.9	334.9	29.0	55.2	92.9	45.0	90.9	313.0
Butachlor + shw at 6 WAS	29.0	77.1	92.9	210.0	90.9	499.9	29.0	55.2	92.9	160.0	90.9	428.0
Two hoe weedings	29.0	77.1	92.9	387.4	90.9	677.3	29.0	55.2	92.9	300.4	90.9	568.4
Three hoe weedings	29.0	77.1	92.9	563.1	90.9	853.3	29.0	55.2	92.9	500.1	90.9	768.1
Weedy check	29.0	77.1	92.9	0.0	90.9	289.9	29.0	55.2	92.9	0.0	90.9	268.0

Nigeria Naira was converted to US dollar by using exchange rate of 362.53 Naira to US$ 1.00

Table 4. Total variable cost, revenue, gross margin and benefit-cost ratio of okra as affected by different weed management methods in early and late wet seasons of 2015

Treatments	Early season				Late season			
	Total variable cost (US$ ha^{-1})	Revenue (US$ ha^{-1})	Gross margin (US$ ha^{-1})	Cost-benefit ratio	Total variable cost (US$ ha^{-1})	Revenue (US$ ha^{-1})	Gross margin (US$ ha^{-1})	Cost-benefit ratio
Propaben	330.3	796.5	493.2	1.5	308.4	1218.4	910.0	2.9
Propaben + shw at 6 WAS	489.9	1042.5	552.6	1.1	418.0	1586.0	1168.0	2.8
Butachlor	334.9	792.9	458.0	1.4	313.0	1161.6	848.6	2.7
Butachlor + shw at 6 WAS	499.9	996.9	497.0	1.0	428.0	1532.4	1104.4	2.5
Two hoe weedings	677.3	773.7	96.4	0.1	568.4	1296.0	727.6	1.2
Three hoe weedings	853.3	1077.0	223.7	0.3	768.1	1640.8	871.9	1.1
Weedy check	289.9	321.9	32.0	0.1	268.0	485.2	216.6	0.8

Nigeria Naira was converted to US dollar by using exchange rate of 362.53 Naira to US$ 1.00; revenue was obtained by multiplying the yield by the steady mean market price (US 0.3 kg^{-1} and 0.4kg^{-1}in early and late wet seasons, respectively). The benefit-cost ratio was calculated by dividing the gross margin by the total variable cost.

Similarly, application of propaben or butachlor plus hoe weeding resulted in higher gross margin and cost-benefit ratio than two and three hoe weeding treatments in both early and late wet seasons (Table 4). Highest cost-benefit ratio (1.2 and 3.0 in the early and late wet seasons) was recorded in plot treated with propaben, while the lowest cost-benefit ratio (0.02 and 0.3 in the early and late wet seasons) was recorded in the weedy plot (Table 4).

DISCUSSION

Effect of weed management methods on weed growth and okra fruit yield

The micro-climate and soil moisture regime of the experimental sites favoured weed diversity in both early and late wet seasons. The prevalence of both annual and perennial weeds, more so, annual and perennial broadleaved and grasses in this study may be a result of high disturbance environment that favour them (Menalled et al., 2001). Higher weed density and biomass recorded in the early than in the late season was possibly because of higher total amount of rainfall experienced in the former (Figure 1). This could further explain higher okra fruit yield recorded in late than the early wet season. Rainfall affects weed species distribution and their competitiveness within a crop community (Shaidul et al., 2011).

In this study, all the weed management methods significantly depressed weed growth with subsequent higher okra fruit yield compared to the weedy check in both early and late wet season. Low weed infestation results in reduced competition for light, nutrients and moisture and consequently adequate supply and use of these resources by okra that could lead to increased fruit yield (Matloob et al., 2015). Although hoe weeding is presently the most common method of weed control in okra in Nigeria, the result of this study showed that pre-emergence herbicide (propaben or butachlor) application was comparable to two hoe weedings in reducing weed growth and increasing okra fruit yield in the early and late wet seasons. However, these treatments could not provide season-long weed control and optimum okra fruit yield. This was probably because two hoe weedings at 3 and 6 WAS and pre-emergence application of propaben or butachlor provided weed control only at the time of weed germination and shortly after emergence, but not at later stages of crop growth. These treatments only controlled the first flush of weeds but did not control the later flushes of weeds, particularly weeds with relatively late time of emergence during the growing season. The inability of hoe weeding and herbicide application alone to provide efficient weed control agrees with Chauhan et al. (2012) and Mishra et al. (2017) that no single method can provide the desired level of weed control efficacy under all situations. Hence the need to integrate different methods and strategies to provide season-long weed control, and widen the weed control spectrum and efficiency for sustainable crop production.

The efficiency of propaben or butachlor plus hoe weeding in providing better weed control and increased okra fruit yield than two hoe weedings or either herbicides applied alone may be attributed to the suppression of weeds by the herbicides at the start of crop growth and the removal of weeds by the hoe weeding, both of which helped to control weeds before setting seed. These results have corroborated the report of Daramola et al. (2019) that integration of herbicide application and hoe weeding is superior to sole herbicide or manual hoe weeding.

Effect of weed management method on economic profitability of okra

Lower cost of production incurred in the late compared to the early wet season may be attributed to the reduction in cost of hoe weeding in the former than in the latter. There was reduction in weed growth due to reduced total amount of rainfall in the late compared to the early wet season. Consequently, the cost of weed control was lower and the yield and return higher in the late compared to the early season. This result is in agreement with Alimi (2005) who observed that okra production was more profitable in the late than in the early wet season. Of all the weed management methods, three hoe weedings incurred the highest cost as a result of accumulated cost of hoe weeding which is usually expensive. On the other hand, weedy plots where weeds were not controlled throughout the crop life cycle had the lowest cost in both early and late wet season. This showed that the cost of weed control takes the bulk of the total production cost as earlier reported by Adigun and Lagoke (2003). Lower cost incurred by propaben and butachlor applied alone or followed by hoe weeding compared to two and three hoe weedings may be attributed to the reduction in labour requirement for herbicide application compared with the labour required for hoe weedings. Comparisons of the economics of different weed control methods have earlier indicated that the overall reduction in production costs associated with herbicides is caused by a massive reduction in the labour required for weeding from 39.2 to 1.3 person-days per hectare (Overfield et al., 2001). The use of herbicides to remove weeds required only 2 hours of labour per hectare, whereas the optimal amount of hand-weeding required per hectare is estimated to be 400 hours (Gouse et al., 2006). The result of this study agrees with the findings of Patil et al. (2014) that manual weeding is very expensive, strenuous and causes a lot of drudgery.

Higher revenue and gross margin recorded with propaben or butachlor followed by hoe weeding compared to two hoe weedings or either herbicide applied alone may be attributed to higher okra fruit yield obtained with the treatments at relatively lower cost. Although three hoe weedings gave the highest revenue, the gross margin obtained was lower than those of propaben and butachlor followed by hoe weeding. This showed that the gain in revenue from three hoe weedings compared to herbicide treatments was nullified by accumulated labour cost for hoe weeding. This result is in agreement with previous report of Khaliq et al. (2012) that weed control with herbicide provided higher gross margin than manual weeding. Hence, the reduced cost-benefit obtained with two and three hoe weedings compared to herbicide treatments.

CONCLUSION AND RECOMMENDATION

Our study showed that okra fruit yield, revenue and net return were higher when weeds were controlled by propaben or butachlor at 2.0 kg a.i ha^{-1} each followed by hoe weeding at 6 WAS compared to sole herbicide application or manual hoe weeding. We conclude that in tropical environments, and particularly in the Nigerian forest savannah transition zone where heavy rainfall and high relative humidity favours rapid and excessive weed growth, combination of pre-emergence herbicide and manual hoe weeding has potential to increase okra yield and net return through efficient weed management at a relatively lower cost. Greater understanding is required on ecology of different weed species and economics of their management in response to varying weed control timing and techniques so that reliance on herbicides could be reduced by following integrated weed management approaches. Information gained in the current study will be used to develop more integrated programs for weed management in okra and to increase its yield and profitability.

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