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Influence of fertilizer application timing and reduced herbicide dosage on weed infestation and maize grain yield

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ABSTRACT

A field trial was conducted in the southern Guinea savanna of Nigeria during 2018 and 2019 to determine the better time of fertilizer application and identify effective weed management options to manage weed infestation and increase maize grain yield. The treatments consisted of two fertilizer application timings and six weed control treatments. The experiment was a 2 x 6 factorial in a randomized complete block design and replicated three times. The fertilizer application at 0 and 6 weeks after seeding (WAS) was found better than application at 2 and 6 WAS in minimising weeds, however both the application timings had no significant influence on maize grain yield. The formulated ready-mixtures (RM) of metolachlor (373 g) + atrazine (375 g) at 1.5 kg/ha followed by (*fb*) one hoeing at 6 WAS, metolachlor (375 g) + atrazine (373 g) at 1.5 kg/ha *fb* nicosulfuron 0.03 kg/ha at 6 WAS, metolachlor + atrazine (RM) 1.5 kg/ha *fb* paraquat 0.7 kg/ha at 6 WAS and metolachlor + atrazine (RM) at 1.5 kg/ha *fb* 2,4-D (900 g) at 1.5 kg/ha significantly (p=0.05) reduced weed infestation by 89.3, 63.8, 48.2 and 39.8%, respectively. The use of metolachlor + atrazine (RM) 1.5 kg/ha *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) 1.5 kg *fb* nicosulfuron 0.03 kg/ha increased maize grain yield by 82.5 and 69.7%, respectively. These treatment combinations integrated with fertilizer timing application at 0 and 6 WAS may be used for efficient, economical and more eco-friendly management of weeds for increasing maize grain yield.

INTRODUCTION

Nigeria is the 14th largest producer of maize in the world (Shahbandeh 2020) with an annual production in excess of 12 million tons (FAO 2020). Weeds have remained one of the major hindrances to Nigeria's quest for food self-sufficiency and environmental management (Tijani *et al.* 2015). Uncontrolled weed growth causes yield losses of 40 – 89% in maize in the tropics (Chikoye *et al.* 2004 and 2005, Imoloame and Omolaiye 2016). Therefore, weed control is crucial for economical production of maize. In Africa, farmers use hand hoeing to control weeds (Ekeleme *et al.* 2016). However, the use of this method has limitations as a result of high weed pressure in farmers' fields, inadequate and high cost of labour, and cumbersome nature of operation which requires great physical energy exertion. These factors have encouraged farmers in Nigeria to prefer the use of herbicides (Best-Ordinioha and Ataga 2017), due to ease of application and effectiveness for weed control. However, most of the herbicides are indiscriminately applied due to high illiteracy rates among the farmers in Nigeria which is adversely affecting the environment, crop yield and human health (Daniel *et al.* 2019). In order to minimize the effect of high input of herbicide into the environment, there is need to reduce the amount of herbicides that will give effective weed control and higher maize yield.

The time of fertilizer application is one of the factors affecting weed infestation and crop yield (Bin Lukangila 2016). It has been reported that optimum rate and time of application of nitrogen fertilizer can enhance maize yield while reducing environmental pollution (Fernandez *et al.* 2009, Nielsen 2013). The best time of fertilizer application for enhanced yield of maize was reported differently as: 10-15 days after planting (DAP) and 35-40 DAP (Abebe and Feyisa 2017), 2 and 6 WAP (Amali and Namo 2015) and at sowing and 6 WAP (Oyinbe *et al.* 1999). Hence, it is essential to find out the best application time and its interaction effect on weed management method. This study was conducted with an objective of identifying the optimal herbicides dosage integration with optimal time of fertilizer application and hoeing for effective weed control and higher yield of maize.

MATERIALS AND METHODS

A field trial was conducted during 2018 and 2019 at the Teaching and Research Farm of the College of Agriculture, Kwara State University, Malete (Latitude 08° 71[1]N and longitude 04° 44[1]E) in the southern Guinea savanna of Nigeria. The experiment was land out in 2 x 6 factorial in a randomized complete block design (RBCD) with three replicates. The fertilizer application timing was assigned to the main plot, while six weed control treatments were in the sub-plots. There were two fertilizer application timings as main plots: i. Fertilizer applications at seeding and 6 weeks after seeding (WAS) and ii. fertilizer application at 2 and 6 WAS. The weed control treatments tested, in the sub-plots, were: pre-emergence application (PE) (a day after seeding) of formulated ready mixture (RD) of metolachlor (373 g) + atrazine (373 g) 1.5 kg/ha followed by (*fb*) one hoeing at 6 WAS; metolachlor (373 g) + atrazine (373 g) 1.5 kg/ha PE *fb* post-emergence application (PoE) of 2, 4-D 1.5 kg/ha, metolachlor (373 g) + atrazine (373 g) (RM) 1.5 kg/ ha PE *fb* nicosulfuron 0.03 kg/ha PoE, metolachlor (373 g) + atrazine (373 g) (RM) 1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE; hoeing twice (HTW) at 3 and 6 WAS and a weedy check. Each of the sub plot in this experiment was of 3m x 3m.

Maize (*SUWAN 1-SR*) was seeded on the 11th and 26th of July, 2018 and 2019 respectively. Emerged seedlings were thinned to two plants per stand spaced at 60 × 60 cm at 3 WAS to maintain 55,555 plants/ha. NPK 15:15:15 and urea fertilizers were used for application to each plot for providing the required nutrients (120 kg N, 60 kg P, 60 kg K) to maize, which was applied in equal split doses. The first dose was applied at planting and at 2 WAS while the second dose was applied at 6 WAS. The pre-emergence application (PE) of formulated mixture of metolachlor + atrazine was applied a day after seeding, while all the post-emergence application (PoE) of nicosulfuron, paraquat and 2,4-D was done at 6 WAS. Harvesting of the mature maize was done on the 8th and 17th of November, 2018 and 2019, respectively. The parameters measured were weed density, weed dry matter (weed biomass), weed cover score, maize plant height, leaf area, 100 seed weight and grain yield.

The weed density (no./m^2**)** was measured at 6 and 12 WAS by counting the total number of weed species occurring within 1.0 m^2 quadrat placed randomly at three locations within each sub-plot. In order to measure weed dry weight (weed biomass) (g/m^2), weed species in a 1.0 m^2 quadrat placed randomly at three locations within each plot were uprooted at 6 and 12 WAS, gathered together and oven-dried at 80°C for two days before weighing. Weed cover was visually assessed at 6 and 12 WAS, using a scale of 1 to 10, where 1 represents no weed cover and 10 complete weed cover.

The maize plant height (cm) was measured from five randomly selected maize plants in a plot and was measured from the soil level to the apex of the tassel at 9 and 12 WAS. The leaf area (cm^2) was obtained by measuring the length and width of leaves from five randomly selected plants from each plot and the average of these measurements was multiplied by a factor of 0.75 to give the leaf area per plant. The100 seed- weight (g) was determined by weighing 100 grains of maize (at 13% moisture content) taken from the maize grains harvested from each sub-plot. The maize grain yield (kg/ha) was weighed to obtain grain yield per net plot which were converted to grain yields per hectare.

Some of the information used for the economic assessment was obtained from the Kwara State Agricultural Development Programme, an agency responsible for agricultural extension Services in Nigeria, while the selling price of maize was obtained from the open market. These, information was used to calculate the production cost (PC), revenue (R) and gross margin (GM).

Production cost (PC) = the cost of inputs and farm operations used (Eni *et al.* 2013). These were cost of seeds, herbicides, insecticides, fertilizers, land preparation, labour for planting, herbicide and insecticide application, weeding, fertilizer application, harvest and processing operations.

$PC = PC_1 + PC_2 + PC_3 + \ldots PCn$———— (1)

Gross revenue (GR) = Crop yield (Y) × Open market price (P)—(2)

Gross margin/Net revenue (NR) = Gross revenue (GR)- Production cost (PC)————(-3)

Benefit-cost ratio= GR/PC ——————(4)

All data were subjected to analysis of variance (ANOVA) using SAS statistical package. Significant differences among treatment means were determined using Tukey Honestly Significant Difference (HSD) test at 5% level of probability.

RESULTS AND DISCUSSION

The total rainfall was 1451.14 and 1432.73mm in 2018 and 2019, respectively. The two peaks of rainfall occurred in May and September during 2018 and in May and June during 2019 (**Figure 1**)

Effect on weeds

The time of fertilizer application had significant (p≤0.05) effect on weed biomass at 6 WAS in 2018, while having no significant effect on weed biomass in 2019 (**Table 1**). At 12 WAS, fertilizer treatments had significant (p≤0.05) effect in 2019. Weed dry matter production was significantly (p ≤ 0.05) higher in the plots treated with fertilizer application at 2 and 6 WAS than those that received fertilizer application at 0 and 6 WAP in 2018 at 6 WAS and in 2019. All the weed control methods significantly (p ≤ 0.05) reduced weed biomass at 6 WAS in 2018. At 12 WAS, treatment combinations of metachlor + atrazine + one SH, metolachlor + atrazine + nicosulfuron and HTW caused significantly (p ≤ 0.05) greater reduction in weed biomass in both years of the experiment than metolachlor + atrazine + 2, 4-D and metolachlor + atrazine + paraquat in 2019 and weedy check in both years. Generally, weed biomass recorded in 2018 was significantly (p ≤ 0.05) lower compared to that in 2019 (**Table 1**). The interaction between fertilizer timing and weed control methods on weed biomass was significant only at 6 WAS in 2018.

Weed density under the two fertilizer timing treatments did not differ significantly at 6 and 12 WAP in both the years. However, there was significant difference (p ≤ 0.05) in weed density between weed control treatments. All the herbicide treatments, herbicide treatment and one SH and HTW at 3 and 6 WAS significantly (p ≤ 0.05) brought down the weed population in both the years at 6 WAS (**Table 1**), however, at 12 WAS, metolachlor + atrazine + paraquat reduced weed density significantly which was comparable with the rest of the treatments in 2018, except metolachlor + atrazine + nicosulfuron and the weedy check which had higher weed density. All the weed control treatments were equally effective in significantly reducing weed density compared to the weedy in 2019 (**Table 1**).

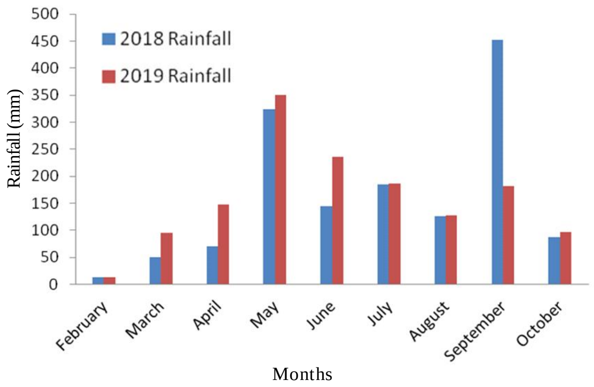

Figure 1. Amount of rainfall (mm) during 2018 and 2019 rainy seasons at the experimental site

Source: Hydrological Section of Lower Niger River Basin and Rural Development Authority, Ilorin, Kwara State, Nigeria

Table 1. Effect of time of fertilizer application and weed control treatments on weed biomass, weed density and weed cover score

Treatment	Rates kg/ha	Weed biomass (g/m²)				Weed density (no./m²)				Weed cover score			
		6 WAS		12 WAS		6 WAS		12 WAS		6 WAS		12 WAS	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Time of fertilizer application (TA)													
0 and 6 WAS		283.3b[1]	1739.2a	992.9a	1173.3b	15.0a[1]	34.4a	19.1a	20.4a	5.9a	4.7a	4.7a	4.3a
2 and 6WAS	-	538.5a	1374.6a	856.4a	2020.8a	14.3a	31.4a	18.9a	28.4a	6.3a	4.7a	3.9a	4.7a
Weed control treatment (WC)													
Metolachlor (373 g) + atrazine (373 g) Ready-mix (RM) PE followed by (*fb*) one hoeing at 6WAS	1.5	226.3b	1100.0a	463.6b	133.4b	15.5b	33.0b	17.3bc	10.7b	5.3b	4.0b	2.0c	2.3b
Metolachlor + atrazine (RM)1.5 kg/ha *fb* 2, 4-D 1.5 kg/ha PoE	1.5+1.5	291.8b	1130.7a	902.9b	2458.9a	12.8b	26.5b	17.3bc	25.3b	6.1b	3.3b	4.2b	4.4b
Metolachlor + atrazine (RM)1.5 kg/ha PE *fb* nicosulfuron 0.03 kg/ha PoE	1.5+0.03	283.3b	1194.7a	1029.6b	992.2b	13.3b	34.0b	21.0b	16.8b	6.2b	4.0b	4.5b	3.6b
Metolachlor + atrazine (RM) 1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE	1.5+0.7	246.2b	1899.8a	658.4b	2232.2a	12.3b	32.3b	11.5c	11.3b	5.4b	3.9b	3.4bc	3.5b
Hoeing twice at 3 and 6 WAS	-	223,1b	1198.1a	360.2b	314.5b	11.0b	16.2b	16.0bc	14.8b	4.2b	2.8b	1.8c	3.2b
Weedy check		1194.7a	2847.3a	2133.3a	3451.2a	23.0a	55.7a	30.8a	67.5a	9.8a	10.0a	10.0a	10.0a
Year		410.9b	1556.9a	924.7b	1597.6a	14.7b	32.92a	19.0a	24.4a	6.1a	4.7b	4.3a	4.5a
Interaction													
TA x WC		S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
TA x year		-	-	-	-	-	-	-	-	-	-	-	-
WC x year		-	-	-	-	-	-	-	-	-	-	-	-
TA x WC x year		-	-	-	-	-	-	-	-	-	-	-	-

WAS=Weeks after seeding, 1=means followed by the same letters within a column are not significantly different at 5% level of probability using Tukey HSD test, NS=Not Significant, S=Significant ; PE =Pre-emergence application; PoE =Post-emergence application; WAS =Weeks after seeding

Fertilizer timing had no significant effect on weed cover, while, significant difference occurred in weed cover among different weed control methods (**Table 1**). Significant ($p \leq 0.05$) reduction of weed cover occurred in plots treated with metolachlor + atrazine *fb* one hoeing at 6 WAS, HTW and all the herbicide combinations compared to the weedy check at 6 WAP. At 12 WAS in 2018, HTW was more effective in lowering the weed cover compared to the other weed control treatments but was comparable to metolachlor + atrazine *fb* one hoeing and metolachlor + atrazine *fb* paraquat, but significantly lower than metolachlor + atrazine *fb* 2, 4-D and metolachlor +atrazine *fb* nicosulfuron, while in 2019, all the herbicide combinations and HWT resulted in significantly ($p \leq 0.05$) lower weed cover than the weedy check. The combinations of all the herbicides tested and herbicide *fb* one hoeing could therefore be applied in rotation to provide effective weed control on commercial farms as alternative to two hand weeding, which has been reported to be tedious, inefficient, time consuming and expensive (Adigun *et al.* 2017, Imoloame and Usman 2018). Furthermore, the use of integrated weed management and combinations of reduced herbicide rates are the two ways to reduce the harmful side effects of herbicides and minimize environmental pollution (Zhang *et al.* 2013). Incorporation of broadcast fertilizer into the soil at 2 WAS after pre-emergence herbicides application, opened up the soil to aeration and encouraged more weed growth in plots treated with fertilizer at 2 and 6 WAS compared to those where fertilizer was applied at 0 and 6 WAS. The significantly higher weed infestation in terms of weed density and biomass in the plots in 2019 compared to 2018, could be attributed to higher rainfall recorded before weed samples were taken in 2019 (1027 mm) compared to 2018 (912.62 mm) at 6 WAP and the superior ability of the crops to suppress weeds in 2018 than 2019 due to better growth and higher total amount of rainfall at later stage of crop growth. The interactive effect of the fertilizer application timing at 2 and 6 WAS and weed control treatments significantly increased the level of weed infestation in the weedy check at 6 WAP. The significantly higher growth of weeds in the weedy check could have caused intense weed competition leading to poor growth and performance of maize.

Maize growth and yield

The maize plant height in the plots treated with fertilizer at 2 and 6 WAS was significantly ($p \leq 0.05$) higher than those in plots where fertilizer was applied before sowing and 6 WAS in 2018, while no significant difference in plant height was observed between the two fertilizer treatments in 2019. The maize plant height at 12 WAS did not differ between the two fertilizer treatments (**Table 2**). But all the weed control treatments resulted in significantly ($p \leq 0.05$) taller plants than the weedy check, except metolachlor + atrazine *fb* nicosulfuron in 2018 and metolachlor + atrazine *fb* paraquat in 2019 in which plant height was similar to that in weedy check. Significantly taller maize plants were produced in 2018 than 2019 (**Table 2**). The interaction effect between fertilizer timing and weed control treatment on plant height was significant at 12 WAS in 2019 (**Table 2**). This interaction significantly ($p \leq 0.05$) reduced maize plant height in the weedy check compared to herbicide plus one hoeing, all the herbicide treatments and HTW at 3 and 6 WAS. Crops growing in plots treated with fertilizer at 2 and 6 WAS possessed significantly ($p \leq 0.05$) larger leaf area than those where application of fertilizer was done before planting in both years at 9 WAS (**Table 2**). All the herbicide treatments, herbicide treatment plus one hoing and HWT resulted in significantly ($p \leq 0.05$) larger leaf area of maize compared to the weedy check in 2019 at 9 WAS. Similar trend was recorded in 2019 at 12 WAS, where all the weed control treatments produced maize with significantly ($p \leq 0.05$) larger leaf area than the weedy check. Additionally, the interactive effect of fertilizer timing and weed control methods on leaf area was significant at 9 WAP in 2019. The leaf area of maize in 2018 was significantly larger than maize leaf area in 2019 (**Table 2**).

Promotion of crop growth in terms of greater plant height and leaf area was achieved with fertilizer application at 2 and 6 WAS compared to fertilizer application before planting and 6 WAS. Furthermore, application of fertilizer at 2 and 6 WAS resulted in significantly taller plants than those from plots treated with fertilizer application timing at 0 and 6 WAS in the two years of the experiment, especially at the early and middle stage of crop growth. This could be attributed to the development of maize root system at 2 WAS which enabled the uptake of higher amount of nutrients and water for better performance than the maize plants in the plots treated with fertilizer before planting, where most of the applied fertilizer must have been leached out by rainfall before the germination and root development of maize. This result corroborates the findings of Amali and Namo (2015) that application of fertilizer at 2 WAS significantly increased mean number of leaves per plant, leave area index and plant height. However, this advantage was short-lived at 12 WAS for plant height and leaf area, as both treatments produced crops that were growing at the same rate. All the weed control treatments resulted in better growth compared to the weedy check especially, metolachlor+ atrazine (RM) *fb* one hoeing, HTW, metolachlor +atrazine (RM) *fb* nicosulfuron, metolachlor + atrazine (RM) *fb* paraquat and metolachlor+ atrazine (RM) *fb* 2, 4-D, as they proved effective control of weeds. Similar result was reported by Khan *et al.* (2020) that utmost maize plant height from herbicide treatments were due to availability of nutrients to maize plants in the absence of weeds These combination of reduced herbicide rates could be added to the list of weed control options for better weed management in both small scale and commercial agriculture in Nigeria. The significant interaction effect between fertilizer timing and weedy check on plant height at 12 WAS and leaf area at 9 WAS could have resulted in significantly shorter and narrower-leaved plants in the weedy check. This could be due the encouragement of increased weed growth when broadcast fertilizer was incorporated in the soil at planting in the weedy check, leading to more intense weed competition and poor maize growth.

The time of fertilizer application had no significant effect on 100-seed weight, while in terms of weed control methods, metolachlor + atrazine (RM) *fb* one hoeing produced maize seeds that were comparable with other herbicide combinations but significantly ($p \leq 0.05$) heavier than the weedy check in both years. However, the other treatments except metolachlor + atrazine (RM) *fb* one hoeing resulted in seeds that were not statistically different from the weedy check (**Table 2**). Plots of HWT had yield significantly ($p \leq 0.05$) higher than the weedy check and was at par with the herbicide combinations in 2018, but in 2019, metolachlor + atrazine (RM) *fb* one hoeing resulted in the highest grain yield which was not statistically ($p \leq 0.05$) different from the other treatments except metolachlor + atrazine (RM) *fb* 2, 4-D, metolachlor + atrazine (RM) *fb* paraquat and the weedy check, which produced significantly ($p \leq 0.05$) lower grain yields (**Table 2**). Maize crop produced significantly heavier seeds and grain yields in 2018 compared to 2019 (**Table 2**) probably due to the early planting, lower weed infestation and higher total annual rainfall recorded in 2018. There was no interaction between time of fertilizer application and weed control treatments on seed weight and grain yields. All herbicide combinations especially, metolachlor + atrazine (RM) *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) *fb* nicosulfuron and HTW at 3 and 6 WAS, gave heavier seeds and grain yield of maize as a result of their ability to provide better selective and season long weed control which minimized weed competition, thus making more growth resources and assimilates available for maize plants for better growth. The low yield in the weedy check could be due to the intense weed competition with the maize plants as reported by Khan *et al.* (2016). Therefore, the afore mentioned weed

Table 2. Effect of time of fertilizer application and weed control method on growth and yield of maize

Treatment	Rates kg/ha	Leaf area (cm^2)				Plant height (cm)				Seed weight(g)		Grain yield (kg/ha)	
		9WAS		12WAS		9WAS		12WAS					
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Time of fertilizer application (TA)													
0 and 6 WAS													
2 and 6 WAS	-	302.6b	293.4b	323.0a	295.1a	74.4b[1]	71.6a	198.5a	150.9a	22.2a	18.5a	3010.5a	1449.6a
	-	389.7a	329.3a	326.2a	321.8a	94.4a	71.4a	205.6a	148.8a	22.1a	18.8a	3094.1a	1125.0a
Weed control method (WC)													
Metolachlor (373 g) + atrazine (373 g) PE *fb* hoeing at 6 WAS	1.5	350.3a	306.7a	317.5a	308.4a	84.3a	69.8a	199.8a	151.8a	22.4a	20.5a	3287.0ab	2036.8a
Metolachlor + atrazine (RM) PE *fb* 2, 4-D PoE													
Metolachlor + atrazine (RM) PE *fb*	1.5+1.5	372.5a	336.6a	361.6a	331.5a	93.3a	71.4a	204.1a	153.8a	22.3a	17.7ab	3148.1ab	878.0ab
nicosulfuron PoE				377.3a	344.3a	82.7ab	69.9a	199.4a	161.5a	23.6a	19.7ab	3105.6ab	1616.5ab
Metolachlor + atrazine (RM) PE fb Paraquat PoE	1.5+0.03	350.0a	313.6a	324.5a	310.9a	87.9a	72.3a	209.4a	149.6ab	22.0a	18.9ab	2963.0ab	1065.2abc
Hoeing twice at 3 and 6 WAS	1.5+0.7	338.9a	322.4a	352.1a	349.9a	89.7a	76.6a	203.5a	159.5a	22.3a	17.8ab	3379.6a	1640.1ab
Weedy Check	-	340.7a	350.8a	214.7b	205.8b	69.1b	69.9a	196.3a	123.1b	20.4b	17.3b	2430.6b	486.3c
Year	-	324.3a	238.0b	324.6a	308.5a	84.4a	71.5b	202.1a	149.87b	22.2a	18.7b	3090.3a	1287.3b
		346.1a	311.4b										
Interaction													
TA X WC		NS	S	NS	NS	NS	NS	NS	S	NS	NS	NS	NS
TA X Year		-	-	-	-	-	-	-	-	-	-	-	-
WC X Year		-	-	-	-	-	-	-	-	-	-	-	-
TA X WC X Year		-	-	-	-	-	-	-	-	-	-	-	-

1=means followed by the same letters within a column are not significantly different at 5% level of probability using Tukey HSD test. NS: Not Significant, S: Significant; WAS: Weeks after seeding, *fb*: Followed by; PE: Pre-emergence application; PoE: Post-emergence application management options, metolachlor + atrazine (RM) *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) *fb* nicosulfuron can serve as alternatives to HTW at 3 and 6 WAS for effective control of weeds on large scale commercial farms. Furthermore, the integration of metolachlor + atrazine (RM) and one hoeing at 6 WAS has reduced the quantity of herbicide used by 25-40% and the integration of metolachlor + atrazine (RM) *fb* nicosulfuron reduced the amount of herbicide used by 25-95% compared to the manufacturer's recommendations. These weed management options are also eco-friendly.

The economic assessment of a combination of fertilizer application timing and weed control treatments on profitability of maize revealed that the combination of fertilizer application timing at 0 and 6 WAS and metolachlor + atrazine (RM) *fb* one hoeing resulted in an average yield (2.79 t/ha) which was at par with the other treatment combinations but significantly ($P < 0.05$) higher than those from a combination of application timing at 0 and 6 WAS *fb* 2 4-D and 0 and 6 WAS *fb* paraquat (1.88 and 1.58 t/ha, respectively) and weed check (1.68 and 1.23 t/ha) (**Table 3**). The combinations of fertilizer timing application of 0 and 6 and 2 and 6 WAS and hoeing twice at 3 and 6 WAS incurred the highest cost of production (₦208,219.3 and ₦ 205,410.4), respectively compared to the other treatment combinations, while the integration of fertilizer timing at 0 and 6 and 2 and 6 WAS and weedy check had the least cost of production (₦ 166,765.6 and ₦ 163,529), respectively. HTW has been reported to be more expensive than chemical or integrated method of weed control in the production of maize (Imoloame 2020). Similarly, the treatment combination of fertilizer application timing at 0 and 6 WAS and metolachlor + atrazine (RM) *fb* one hoeing generated highest gross revenue (₦ 335,028.00) followed by treatment combinations of 0 and 6 WAS and HTW (₦ 326,904.00), 0 and 6 WAS and metolachlor + atrazine (RM) *fb* nicosulfuron (₦ 318,996.00) and 2 and 6 WAS and metolachlor + atrazine *fb* one hoeing (₦ 303,828.00), in the decreasing order of revenue generation. The highest gross margin emanated from treatment combinations of fertilizer timing at 0 and 6 WAS *fb* metolachlor + atrazine (RM) *fb* one hoeing (₦ 151,174.00) and 0 and 6 WAS and metolaclor + atrazine (RM) *fb* nicosulfuron (₦ 134,525.00), while the least gross margin resulted from treatment combination of 0 and 6 WAS and metolachlor + atrazine (RM) *fb* 2, 4-D and 2 and 6 WAS and weedy check (₦ 764.00 and ₦ -11,119.00). The benefit cost ratio was highest in the treatment combinations of 0 and 6 WAS and metolachlor + atrazine *fb* one hoeing (1.748) and 0 and 6 WAS *fb* metolachlor + atrazine (RM) *fb*

Table 3. Economic analysis of the effect of weed control treatments and fertilizer application timing on profitability in maize production

Production activity	0&6WAS* M+A (RB) *fb* 1 H**	2&6WAS M+A (RB) *fb* 1 H	0&6WAS M+A (RB) *fb* 2, 4-D	2&6WAS M+A (RB) *fb* 2, 4-D	0&6WAS M+A (RB) *fb* NS	2&6WAS M+A (RB) *fb* NS	0&6WAS M+A (RB) *fb PQ*	2&6WAS M+A (RB) *fb PQ*	0&6WAS HT 3 and 6 WAS	2& 6WAP HT 3 and 6WAS	0&6 WAS Weedy check	2&6 WAS Weedy check
Land preparation/ha	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Seed/ha	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Planting/ha	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Fertilizer cost /ha	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000
Application of fert. (1st & 2nd doses)	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
1st Hoeing at 3 WAS												
2nd hoeing at 6 WAS	-	-	-	-	-	-	-	-	17,000	17,000	-	-
Cost of herbicide/ ha	-	-	-	-	-	-	-	-	17,000	17,000	-	-
Cost of herb. Application/ha	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	-	-	-	-
Cost of pesticide/ha	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	-	-	-	-
Cost of pesticide application	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Labour for processing	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
	20,000	18,138	19,042	16,415	11,325	15,482	13,489	15,367	19,519	16,440	12065	8,829
Total cost of prod.(₦)	191,700	189,838	190,743	188,115	183025	187182	185,183	187067	208,219	205140	166765	163529
Average yield (kg/ha)	2,792a	2,532a	2,658a	2,291a	1,581b	2,161a	1,883b	2,145a	2,725a	2,295a	1,684b	1,232c
Gross Revenue (₦).	335,028	303,828	318,996	274,980	189,708	259,344	225,960	257,412	326,904	275,400	202,116	147,900
Gross Margin(₦)	151,174	112,128	134,525	86,453	764	69,428	68,051	63,958	121,651	71,694	45,471	-11,119
Benefit/cost ratio	1.748	1.600	1.672	1.462	1.037	1.386	1.382	1.376	1.570	1.342	1.212	0.904

WAS: weed after seeding; *fb*: Followed by; PE: Pre-emergence application; PoE: Post-emergence application; N: Nigeria Naira; Selling price of maize in the open market= N 120 / kg; *Fertilizer application timings: 0&6WAS; 2&6WAS; N =Naira; **Treatments: M+A (RB) fb 1 H = Metolachlor (373g) + atrazine (373 g) Ready-mix (RM) PE followed by (*fb*) one hoeing at 6WAS; M+A (RB) *fb* 2, 4-D = Metolachlor + atrazine (RM)1.5 kg/ha *fb* 2, 4-D 1.5 kg/ha PoE; M+A (RB) *fb* NS = Metolachlor + atrazine (RM)1.5kg/ha PE *fb* nicosulfuron 0.03 kg/ha PoE; M+A (RB) *fb PQ* = Metalachlor + atrazine (RM)1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE; HT 3 and 6 WAS = Hoeing twice at 3 and 6 WAS nicosulfuron (1.672). These treatment combinations did not only generate higher gross revenue compared to the other treatments, they resulted in higher gross margin and benefit - cost ratio and are therefore recommended for adoption in the southern Guinea savanna of Nigeria.

It was concluded that both the fertilizer application timings tested *i.e.* at 0 and 6 WAS can be recommended along with metolachlor+ atrazine at 1.5 kg/ha *fb* one hoeing at 6 WAS and metolachlor+ atrazine *fb* nicosulfuron at 0.03 kg/ha at 6 WAS as weed management options for effective weed control, better growth, higher yield and economic returns in maize production in the southern Guinea savanna of Nigeria.

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