Evaluation of herbicide mixtures and manual weed control methods in maize (*Zea mays* L.) production in the southern guinea agro-ecology of Nigeria

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Abstract

Field trials were conducted in 2015 and 2016 cropping seasons to evaluate some herbicide mixtures and manual weed control method in the production of maize in the southern Guinea savanna of Nigeria. The experiment consisted of 10 treatments as follows: metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}, metolachlor + atrazine at 2.0+2.5 kg a.i. ha^{-1}, metolachlor + atrazine at 3.0 + 3.0 kg a.i. ha^{-1}, pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}, pendimethalin + atrazine at 2.0 + 2.5 kg a.i. ha^{-1}, pendimethalin+ atrazine at 3.0+3.0 kg a.i. ha^{-1}, metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), pendimethlin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), hand weeding at 3 and 6 WAS and a weedy check. These treatments were laid out in randomized complete block design (RCBD) with three replicates. Data collected included weed dry matter, weed density, relative importance value (RIV%) of weed species, leaf area, plant height and grain yield of maize. Also, economic assessment of the weed control methods was carried out. Results showed that metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0kg a.i. ha^{-1} plus one SHW at 6 WAS significantly reduced weed infestation and gave higher grain yield of maize and economic returns. These methods are therefore recommended to farmers as alternatives to two hand weeding at 3 and 6 WAS.

Keywords: Chemical weed control, Hand weeding, Herbicide mixture, Maize productivity, Weed infestation

Introduction

Maize (*Zea mays L.*) is the third most important cereal crop in the world after wheat and rice (MINFAL, 2003). In the developing countries it is a major source of income to many farmers (Tagneet et al., 2008).

According to Food and Agricultural Organization statistics, 822.7 million metric tonnes of maize were produced worldwide in 2008. Out of this, Africa produced 53.2 million metric tonnes, while Nigeria produced 7.3 million metric tonnes in 2009 (FAO, 2011).

Despite its importance, the yield of maize obtained in Nigeria is far below expectation due to numerous factors which include weed infestation, low soil fertility and availability of labour. Yield losses between 60-80% have been attributed to uncontrolled weed infestation in maize (Lagoke et al., 1998) and this finding was confirmed by Imoloame and Omolaiye (2016), who reported 89% yield loss inmaize as a result of uncontrolled weed infestation.

Manual weeding is the commonest method of weed control in Nigeria. The traditional method is back-breaking, which offers little hope for expanding the

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present farm size. Hoe weeding is labour intensive, expensive and strenuous. Ekeleme (2009) reported that 25 -55% of the total cost of production is spent on labour and weeding operations.

Chemical weed control is a practical and economic alternative to hand weeding. If herbicide is applied appropriately it could prevent weed infestation from planting to harvesting and promote higher yields by allowing closer crop spacing and therefore higher plant population.

Though chemical weed control has many advantages over hoe weeding, there is the possibility of reducing the herbicide rates in order to cut cost and mitigate the problem of environmental build-up of herbicide residues and herbicide resistant weeds. This calls for Integrated Weed Management (IWM) strategy which is the combination of two or more weed control methods for more effective and efficient weed control than a single method. This approach considers the use of cultural, mechanical and chemical control options that are both feasible in specific cropping systems and permitted by socio-economic conditions (Norsworthy et al., 2012; Vencill et al., 2012; Ganie et al., 2014)

Most of the available research carried out on methods of weed control in maize have been in the northern Guinea savanna of Nigeria. Also, the high cost of weed control coupled with the high labour demand of hoe weeding and the need to protect the environment has driven the desire for a method of weed control that will not only be safe, effective and efficient in minimizing weed density, but will also lead to higher grain yield of maize.

The objectives of this research were to determine the weed control method that would result in effective and efficient weed control and also give higher grain yield of maize.

Materials and Methods

A field experiment was conducted during the 2015 and 2016 rainy seasons at the Teaching and Research (T&R) Farm of Kwara State University, Malete, (lat. 08°, 71'N; long.04°44'E) at 360 m above sea level. The experiment consisted of 10 treatments, namely, metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}, metolachlor + atrazine at 2.0+2.5 kg a.i. ha^{-1}, metolachlor + atrazine at 3.0 + 3.0 kg a.i. ha^{-1}, pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}, pendimethalin + atrazine at 2.0 + 2.5 kg a.i. ha^{-1}, pendimethalin + atrazine at 3.0+3.0 kg a.i. ha^{-1}, metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), hand weeding at 3 and 6 WAS and a weedy check.These treatments were laid out in a randomized complete block design (RCBD) and replicated three times. The maize variety was used was SUWAN-1-SR which was sown on the11th and 14th of July, 2015 and 2016 respectively. The crop was spaced at 75 cm x 25 cm to give a plant population of 53,333 ha^{-1}. Herbicides were applied a day after planting with a CP15 knapsack sprayer and a green nozzle which were calibrated to deliver a spray volume of 250 litre ha^{-1}, Karate insecticide containing 2.5% lambdacyhalothrin at the rate of 30 ml in 10 litres of water was applied three times beginning from 6 WAS to control army worms. Fertilizer was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 K_2O. These were provided with a compound fertilizer *viz*., 15:15:15. Harvesting was done on a net plot of 9 m^2 after the rows at the edges on both sides of the gross plot (16 m^2) were discarded to reduce error. The parameters measured included weed density, weed cover score, weed dry weight, plant height, leaf area and grain yield. The relative importance value (RIV) of each weed species was determined after the weeds were collected from the quadrat and before they were oven dried. The RIV was computed as follows:

$$RIV = \frac{RD + RF}{2} \text{(Wentworth et al., 1984)}$$

Relative density (RD) was determined by dividing the total number of individuals of a weed species in all the quadrats by the total number of all the weed species in all the quadrats multiplied by 100. The percentage relative frequency was calculated as the number of occurrence of a species in all the quadrats divided by the total of occurrence of all species in all the quadrats multiplied by 100 (Das, 2011).

Data analysis

The data collected was subjected to analysis of variance using Assistat 7.7, 2017 version Statistical Package and where F value was significant, the means were separated using the Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Economic analysis

The economic analysis was carried out using partial budgeting (Okoruwa et al., 2005) to calculate the gross margin (profit) as follows:

GM = TR- VC

TR = (Ys X Ps)

VC = M + L

Where: GM =Gross margin ha^{-1} for each treatment

TR= Total revenue, Naira ha^{-1} for each treatment

VC= Variable cost, Naira ha^{-1} for each treatment

Ys = maize grain yield (kg ha^{-1}) for each treatment

Ps = Price of maize per kg The price of 1 kilogram of maize was obtained from the open market to calculate the income per total revenue.

M =Value of material input (seeds, fertilizer, insecticide, herbicide)

L =Value of Labour (land preparation, planting, insecticide, herbicide, and fertilizer application, harvesting, processing and packaging)

The cost: benefit ratio was calculated using the method of Joshua and Gworgwor (2001) as follows:

Cost benefit ratio = $\frac{TCP}{I}$ where TCP is total cost of production and I is income per revenue

Results and Discussion

Rainfall

The total amount of rainfall recorded in 2015 was 1010.5 mm, with the month of September having the highest rainfall, while January, February, April and August had low rainfall. In 2016, higher rainfall of 1,493.4 mm was recorded which was evenly distributed (Fig.1).

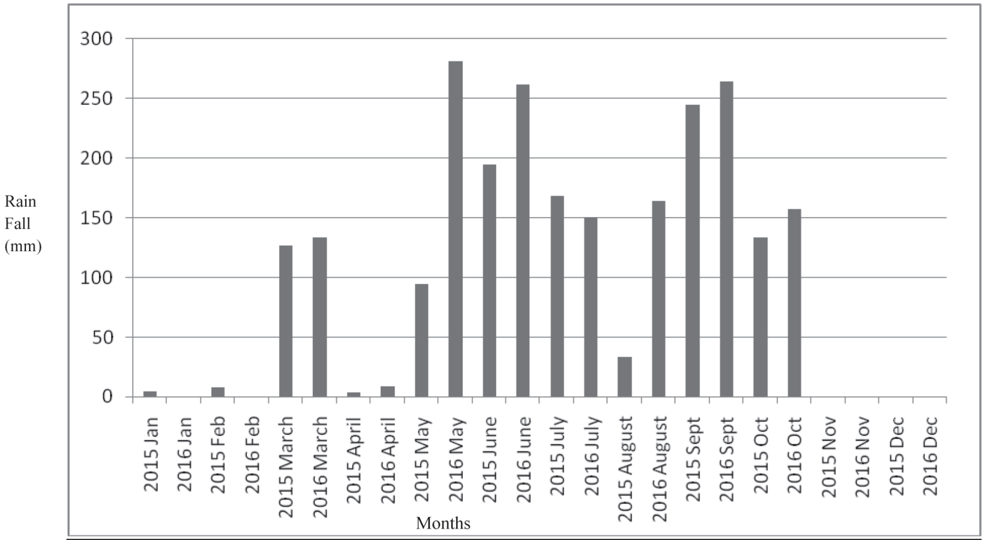

Figure 1. Monthly rainfall (mm) figures in 2015 and 2016 seasons at the Teaching and Research Farm of Faculty of Agriculture, University of Ilorin, Kwara State, Nigeria

Physico-chemical analysis of the soil of the experimental site

The soil at experimental site was sandy loam and slightly acidic. The nitrogen and available phosphorus content of the soil was low and inadequate (Table 1).

Table 1. Physico-chemical properties of the soil (0 – 30 cm) collected of the experimental site, 2015

Soil properties	
Physical Properties	
Sand (g kg^{-1})	812
Silt (g kg^{-1})	94.0
Clay (g kg^{-1})	94.0
Textural Class	Loamy Sand
Chemical Propertiesp	
H in water (1:2.5)	6.2
Total organic carbon (g kg^{-1})	13.2
Total nitrogen (g kg^{-1})	1.4
Available phosphorus (mg kg^{-1})	6.6
Exchangeable cations (C mol^{-1} kg^{-1})	
K	0.17
Mg	2.23
Ca	1.4
Exch. micronutrients (Cmol kg $^{-1}$)	
Mn	184.0
Fe	82.0
Cu	1.68
Zn	1.92
Na	0.18

Relative Importance Value (RIV%) at the experimental site

The relative importance value of weed species infesting the maize crop under each treatment is presented in Table 2. *Paspalum scrobiculatum* was the most dominant weed species both within and across all the treatments at 6 and 12WAS in 2015. The total number of weed species increased across treatments with some broadleaved weeds like *Gomphrena celosoides* and *Hyptis suaveolens* becoming dominant between 6 and 12 WAS (Tables 2 and 3). *Paspalum scrobiculatum* appears to be the most predominant weed species infesting maize within and across treatments at 6 and 12 WAS in maize plot. This could be as a result of the inability of the treatments to fully control this weed species which was also well adapted to the environment. The adaptive capacity of this weed species made it more persistent and competitive with the maize crop. This is in line with the findings of Imoloame and Omolaiye (2016), that weed species with the highest relative importance value in maize were *Paspalum scobiculatum* and *Digitaria horizontalis*. The significant reduction in the yield of maize in the weedy check could have resulted from the predominance of *Paspalum scrobiculatum*. There was an increase in the number of weeds species at 12 WAS under each treatment. This could have resulted from the germination of more weed species with time as the effect of the herbicides expired. Also, the appearance of broadleaved weeds as dominant weed species at 12 WAS suggest that broadleaved weed flushes comes up later in the season probably because they are buried at a greater depth of the soil. Deat et al. (1980) reported that 60-75% of total grassy weeds as against only 30-35% broad leaved weeds emerged during first 15 days of an intensively cultivated field in Ivory Coast.

Effect of herbicide mixtures and manual weed control on weed dry matter, weed cover and density in maize crop

Pre-emergence application of pendimethalin + atrazine and metolachlor+ atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS and two hand weedings at 3 and 6 WAS caused a significant reduction in weed dry matter than the other methods of weed control at both 6 and 12 WAS in 2016. (Table 4). Metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS and hand weeding at 3 and 6 WAS were more effective in significantly reducing both weed density and weed cover compared to the other treatments (Table 5). The ability of metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS and two hand weeding at 3 and 6 WAS to significantly reduce weed dry matter, weed density and weed cover proves the effectiveness and efficacy of these weed control methods. These different herbicide mixtures plus one SHW can be used in rotation for effective weed control in maize. The integration of herbicides

Table 2. Relative importance value (RIV%) of weed species at the experimental site at 6 WAS, 2015

	Treatment						(P+A+oneSHW@ 6 WAS1.0+2.0)	(M+A+oneSHW@ 6 WAS1.0+2.0)			
Weed Species	P+A 1.0 +2.0	P+A 2.0+2.5	P+A 3.0+3.0	M+A 1.0 +2.0	M+A 2.0+2.5	M+A 3.0+3.0	D + A + SHW 1.0 +2.0	M +A + SHW 1.0 +2.0	WAS	Weedy Check	Overall RIV%
Grasses											
Paspalum scrobiculatum	51.0	48.7	46.6	42.0	53.8	37.7	70.2	56.0	45.7	42.3	49.4
Digitaria horizontalis			6.2	6.0		12.6		12.5		3.6	4.1
Setaria barbata	7.5			15	11.4	11.2		31.5		7.0	8.4
Rottboellia cochinchinensis	10.9			12	26.9	38.6					8.8
Chloris pilosa									10		1
Sedges											
Mariscus alternifolius	10.7	29.2	11.8	13.2			7.5		8.5	10.4	9.1
Cyperus rotundus			9								0.9
Pycreus lanceolatum		5.4	4.5						14	11.4	3.5
Kyllinga squamulata		5.4					7.5		8.5	2.9	2.4
Cyperus esculentus	6.1										0.6
Broadleaf											
Gomphrena celosoides	8.8		5.5	6.0	8				7.0	9.4	4.5
Hyptis suaveolens		6.1	4.8						6.5	3.2	2.1
Aeyratum conyzoides			6.2								0.6
Euphorbia heterophylla			5.2								
Vernonia galamensis							14.9			6	2.1
Ludwigia deccurens	6.1									34.1	4.0
Commelina benghalensis		5.4									0.5
Portulaca oleracea				6							0.6
Total	7	6	9	7	4	4	4	3	7	10	

with one supplementary hoe weeding has been found to be very effective in the control of weeds and for promoting higher yields in various crops (Peer et al., 2013; Veeramani et al., 2001; Imoloame, 2014).

Effect of herbicide mixtures and manual weed control methods on the growth of maize

All the herbicide treatments increased plant height significantly as compared to the weedy check at 6 WAS, however, with time at 12 WAS, hand weeding at 3 and 6 WAS gave significantly taller plants than the other treatments except metolachlor + atrazine and pendimethalin at 1.0 + 2.0 kg a.i. ha^{-1} and metolachlor + atrazine at 3.0 + 3.0 kg a.i. ha^{-1}, which produced comparable taller plants (Table 6). Two hand weedings at 3 and 6 WAS and the two different herbicide mixtures integrated with one SHW at 6 WAS resulted in significantly taller plants than the other treatments, probably due to their ability to significantly reduce weed infestation, which could have minimized weed competition and made sufficient growth resources (moisture, plant nutrients, light) available for utilization and better performance by maize crop. Pre-emergence application of pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW resulted in leaf area significantly greater than the weedy check but was comparable to the other weed control methods including two hand weedings at 9 WAS (Table 7). However, pendimethalin + atrazine and metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW, all the rates of metolachlor + atrazine and two hoe weeding gave significantly larger leaves in both years at 12 WAS. The larger leaf area of the maize plants produced from plots treated with metolachlor + atrazine and pendimethalin + atrazine at 1.0+2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS is an additional proof of their efficacy to promote effective weed control and the utilization of growth resources for better growth. The larger leaf area confers advantage to maize as it provides a larger surface for the capture of more solar radiation for increased photosynthesis and higher yield.

*Table 3.*Relative importance value (RIV%) of weed species at the experimental site at 12 WAS, 2015

	Treatment						(P+A+oneSHW@ 6 WAS1.0+2.0)	(M+A+oneSHW@ 6 WAS1.0+2.0)			
Weed Species	P+A 1.0 +2.0	P+A 2.0+2.5	P+A 3.0+3.0	M+A 1.0 +2.0	M+A 2.0+2.5	M+A 3.0+3.0	D + A + SHW 1.0 +2.0	M +A + SHW 1.0 +2.0	WAS	Weedy Check	Overall RIV%
Grasses											
Paspalum scrobiculatum	29.6	23.2	21.8	24.8	21.6	21.5	27.6	25.7	24.4	12.1	23.2
Digitaria horizontalis				14.2	30.0				4.7	16.6	6.6
Setaria barbata	18.5		4.1	22.9	24.4	31.7	5.2	6.5	18.3	24.4	15.6
Rottboellia cochinchinensis	4.4	3.9		2.9	6.7		6.8	3.4	3.1	2.1	3.3
Chloris pilosa	2.5							5.1	2.7	1.7	1.2
Setariapumila	4.9										0.5
Mariscus alternifolius		3.9								2.3	0.62
Dactylocteniumaegyptium				2.9						4.1	0.7
Brachiariaalata										1.7	0.2
Sedges											
Cyperusiria	2.5								2.7	1.7	1.2
Cyperusrotundus										2.1	0.21
Pycreuslanceolatum				2.9							0.3
kyllingasquamulata								3.7			0.4
Cyperusesculentus	6.7	11	7.8	5.8			12.6	5.7	7.4	7.4	6.4
Cyperusdifformis									2.7	1.7	0.3
Killingaerecta		17	19.3				17		6.4		6
Broad leaf											
Gomphrena celosoides	3.2		14.7	5.3	3.5	24.5	6.8	17.6	7.0	5.8	8.8
Hyptis suaveolas	11.6	16.6	4.5	5.4	7.2	11.8	6.8	18.3	8.9	4.2	8.4
Euphorbia heterophilla			3.7			5.0					0.9
Vernonia galamensis	5.5	7.4	5.3	10.2		5.7	13.1	9.8	5.8	5.4	6.8
Leucas martinicensis			6.7	2.9	3.2					2.6	1.5
Commelina benghalensis	10.6	7.1	12.4		3.5						4.0
Hyptis lanceolata							3.6	5.1			1.3
Portulaca oleracea										2.2	0.2
Total	11	8	10	11	8	6	9	10	13	17	

Table 4. Effect of herbicide mixtures and manual weed control methods on weed dry matter (kg ha^{-1})

Treatment	Rate kg a.i. ha^{-1}	6 WAS[1]			12 WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0+2.0	229.8^{a2}	1647.3^{b}	938.6^{ab}	537.5^{ab}	2199.8^{bc}	1368.6^{b}
P+A	2.0+2.5	234.2^{a}	1494.2^{b}	864.2^{b}	420.3^{ab}	1899.8^{bc}	1160.1^{bc}
P+A	3.0+3.0	112.5^{a}	696.5b^{c}	404.5^{b}	426.4^{ab}	2177.8^{bc}	1302.1^{b}
M+A	1.0+2.0	544.9^{a}	980.0b^{c}	762.4^{b}	284.6^{b}	2288.9^{bc}	1286.7^{b}
M+A	2.0+2.5	504.3^{a}	870.0b^{c}	687.1^{b}	469.2^{ab}	2844.5^{b}	1656.8^{ab}
M+A	3.0+3.0	124.4^{a}	1228.0^{bc}	676.2^{b}	103.6^{b}	1433.2^{cd}	1768.4^{bc}
P+A+oneSHW @ 6 WAS	1.0+2.0	289.8^{a}	66.9^{d}	178.3^{b}	134.8^{b}	355.6^{d}	245.2^{cd}
M+A+oneSHW a@ 6WAS	1.0+2.0	155.9^{a}	185.3^{d}	170.6^{b}	163.9^{b}	233.3^{d}	198.6^{d}
Weeding @ 3&6 WAS	-	43.3^{a}	418.7^{cd}	231.9^{b}	261.5^{b}	344.5^{d}	302.9^{cd}
Weedy check	-	252.9^{a}	2973.6^{a}	1613.2^{a}	857.8^{a}	4088.5^{a}	2473.2^{a}

P+A = Pendimethalin + Atrazine; M+A = Metolachlor+Atrazine; 1 = Weeks after sowing; 2 = Means in a column followed by the same alphabet (s) are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

Table 5. Effect of herbicide mixture and manual weed control methods on weed cover score and density

Treatment	Rate kg a.i. ha^{-1}	Weed density per m^2 12 WAS[1]			Weed cover 6 WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0+2.0	18.2[b]	45.0[b2]	31.6[b]	4.3[b]	5.7[bc]	5.0[b]
P+A	2.0+2.5	26.1[b]	38.0[b]	32.0[b]	1.8[bc]	4.7[bc]	3. 3[bc]
P+A	3.0+3.0	13.8[b]	52.7[b]	33.2[b]	1.3[c]	4.2[bc]	2.7[bc]
M+A	1.0+2.0	17.2[b]	26.0[b]	21.6[b]	1.5[c]	7.7[ab]	4.6[bc]
M+A	2.0+2.5	30.1[b]	32.8[b]	31.5[b]	1.8[bc]	7.0[ab]	4.4[bc]
M+A	3.0+3.0	21.5[b]	41.2[b]	31.4[b]	1.1[c]	6.5[ab]	3.8[bc]
P+A+oneSHW @ 6 WAS	1.0+2.0	10.2[b]	12.2[b]	11.2[b]	3.3[bc]	1.3[d]	2.3[bc]
M+A+oneSHW @ 6WAS	1.0+2.0	15.1[b]	16.5[b]	15.8[b]	2.7[bc]	1.3[d]	2.1[c]
Weeding @ 3&6 WAS	-	14.6[b]	20.6[b]	17.6[b]	1.1[c]	2.3[cd]	1.7[c]
Weedy check	-	45.7[a]	147.6[a]	142.2[a]	10.0[a]	10.0[a]	10.0[a]

P+A = Pendimethalin + Atrazine; M+A = Metolachlor+Atrazine; 1 = Weeks after sowing; 2 = Means in a column followed by the same alphabet(s) are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

Table 6. Effect of herbicide mixtures and manual weed control methods on plant height

Treatment	Rate kg a.i. ha^{-1}	Plant Height (cm)					
		6 WAS[1]			12 WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0+2.0	63.3[a]	66.5[ab]	64.9[ab]	186.3[a]	159.1[b]	172.7[bc2]
P+A	2.0+2.5	71.5[a]	68.4[ab]	69.9[a]	173.6[a]	158.2[b]	165.8[bc]
P+A	3.0+3.0	58.5[a]	61.9[ab]	60.2[ab]	180.9[a]	146.2[b]	163.6[bc]
M+A	1.0+2.0	56.1[a]	57.9[bc]	57.0[bc]	193.3[a]	147.5[b]	170.4[bc]
M+A	2.0+2.5	61.3[a]	64.8[ab]	63.0[ab]	201.3[a]	146.2[b]	173.7[bc]
M+A	3.0+3.0	56.8[a]	65.1[ab]	60.9[ab]	200.9[a]	148.7[b]	174.8[ab]
P+A+oneSHW @6 WAS	1.0+2.0	57.7[a]	77.0[a]	67.4[ab]	186.0[a]	172.5[b]	179.2[ab]
M+A+oneSHW @ 6WAS	1.0+2.0	63.3[a]	68.9[ab]	65.3[ab]	203.9[a]	176.3[b]	190.1[ab]
Weeding @ 3&6 WAS	-	59.3[a]	76.1[ab]	67.7[ab]	190.2[a]	217.1[a]	203.7[a]
Weedy check	-	50.8[a]	54.1[c]	52.5[c]	165.3[a]	148.6[b]	156.9[c]

P+A = Pendimethalin + Atrazine; M+A = Metolachlor+Atrazine; 1 = Weeks after sowing; 2 = Means in a column followed by the same alphabet (s) are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

Effect of herbicide mixtures and manual weeding on grain yield of maize

Two hoe weedings at 3 and 6 WAS produced grain yields that were comparable to metolachlor + atrazine and pendimethalin+ atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS, but was significantly higher than the rest of the treatments and the weedy check in both years (Table 8). This is probably a result of better weed control provided by these treatments which gave rise to better growth and higher grain yields.. This result is similar to that of Imoloame (2014) andVeeramani et al. (2001), who reported increase in grain yield as a result of the use of herbicide application plus one SHW.

Economic assessment of the use of different methods of weed control

The highest grain yield of maize (2,814 kg ha^{-1}) was obtained from plots treated with pre-emergence application of metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW followed by pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}, while the least yield (1862 kg ha^{-1}) was produced by metolachlor + atrazine at 2.0+2.5 kg a.i. ha^{-1} in 2015 (Table 9). However in 2016, hand weeding at 3 and 6 WAS resulted in the highest maize yield (3,028 and 2782 kg ha^{-1}) followed by metolachlor + atrazine at 1.0+ 2.0 kg a.i. ha^{-1} plus one supplementary hoe weeding at 6 WAS (1956 and 2385 kg ha^{-1}).

Table 7. Effect of herbicide mixtures and manual weed control methods on leaf area

Treatment	Rate kg a.i.ha^{-1}	Leaf Area (cm^2)					
		9 WAS			12 WAS[1]		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0+2.0	401.4[a2]	200.3[ab]	300.8[a]	324.4[bc]	219.5[b]	271.9[ab]
P+A	2.0+2.5	364.4[ab]	218.9[ab]	291.7[a]	281.2[bc]	273.3[b]	277.3[ab]
P+A	3.0+3.0	378.0[ab]	218.5[ab]	298.3[a]	325.4[bc]	278.6[b]	302.0[ab]
M+A	1.0+2.0	325.2[ab]	200.1[ab]	262.7[a]	341.7[ab]	258.1[b]	299.9[ab]
M+A	2.0+2.5	326.2[ab]	200.9[ab]	263.6[a]	340.2[ab]	270.1[b]	305.1[a]
M+A	3.0+3.0	334.3[ab]	176.2[ab]	255.2[a]	395.9[a]	267.6[b]	331.8[a]
P+A+oneSHW @ 6 WAS	1.0+2.0	393.5[a]	244.4[a]	318.9[a]	276.1[bc]	304.4[ab]	290.3[a]
M+A+oneSHW@6WAS	1.0+2.0	382.6[ab]	230.1[ab]	306.4[a]	343.7[ab]	282.9[b]	313.3[a]
Weeding @ 3&6 WAS	-	347.9[ab]	199.6[ab]	273.8[a]	298.8[bc]	395.5[a]	347.1[a]
Weedy check	-	300.3[b]	149.6[b]	224.9[a]	255.0[c]	201.4[b]	228.2[b]

P+A = Pendimethalin + Atrazine; M+A = Metolachlor+Atrazine; 1 = Weeks after sowing; 2 = Means in a column followed by the same alphabet (s) are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

Hand weeding at 3 and 6 WAS was the most expensive method of weed control per hectare (N127,300 ha^{-1}) among the treatments, while the lowest (N107,300) was from weedy plots in both years. This result is corroborated by the findings of Imoloame (2014) and Adigun and Lagoke (2003) that manual weeding is very expensive. In 2015, metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1}plus one SHW at 6 WAS followed by two hand weeding at 3 and 6 WAS and pendimethalin + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS generated the highest income (N337, 776) (N304, 440) and (N271,020) ha^{-1} respectively, while weedy check resulted in the lowest income (N81, 108). However

Table 8. Effect of herbicide mixtures and manual weed control methods on grain yield

Treatment	Rate kg a.i. ha^{-1}	Grain Yield (kg ha^{-1})		
		2015	2016	Mean
P+A	1.0+2.0	2333.3[a2]	1300.8[bc]	1817.1[bc]
P+A	2.0+2.5	2396.3[a]	792.3[c]	1594.3[bc]
P+A	3.0+3.0	2096.3[a]	506.8[c]	1301.5[cd]
M+A	1.0+2.0	1999.9[a]	253.4[c]	1126.7[de]
M+A	2.0+2.5	1862.9[a]	481.8[c]	1172.4[de]
M+A	3.0+3.0	2258.5[a]	450.1[c]	1304.7[cd]
P+A+oneSHW @ 6 WAS[1]	1.0+2.0	2258.5[a]	1831.9[b]	2045.7[ab]
M+A+oneSHW[3] @ 6WAS	1.0+2.0	2814.8[a]	1956.6[b]	2385.7[ab]
Weeding @ 3&6 WAS	-	2537.0[a]	3028.3[a]	2782.7[a]
Weedy check	-	695.9[b]	591.2[c]	633.6[e]

P+A = Pendimethalin + Atrazine; M+A = Metolachlor+Atrazine; 1 = Weeks after sowing; 2 = Means in a column followed by the same alphabet (s) are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

in 2016, higher income was obtained from two hand weeding at 3 and 6 WAS (N666, 336) and (N485, 388) ha^{-1} respectively, followed by metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS (N430, 452) and (N384, 114). The lowest revenue was got from metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} (N55, 784 and N147, 886 ha^{-1}). Metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS generated the highest income in 2015, because of its ability to produce higher grain yield of maize. However, in 2016 two hoe weeding produced the highest grain yield and therefore gave higher revenue.

The highest gross margin per profit (N358,088) ha^{-1} resulted from the plots that were manually weeded 3 and 6 WAS, followed by metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS (N259,284) ha^{-1}, while the lowest profit per gross margin (N-1,714) ha^{-1} was recorded for weedy check and metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} (N31,056) (Table 9). This is similar the findings of Imoloame (2014) who recommended the pre-emergence application of metolachlor+diuron at 1.5 + 0.5 kg a.i. ha^{-1} plus one SHW at 6 WAS for higher yield, profitability and economic returns in soybean production.

Weedy check followed by metolachlor + atrazine

Table 9. Economic assessment of herbicide mixtures and manual weed control in the production of maize, 2015 and 2016

Treatment	Rate kg a.i. ha^{-1}	Grain Yield kg ha^{-1}		Cost of Production			Total Revenue			Gross Margin	Cost Benefit Ratio		
		2015	2016	2015	2016	Mean	2015	2016	Mean		2015	2016	Mean
P+A	1.0+2.0	2333.3^{a1}	1300.8^{bc}	117,500	117,500	117,500	279,996	286,176	283,086	165,586	1:0.420	1:0.441	1:0.415
P+A	2.0+2.5	2396.3^{a}	792.3^{c}	122,460	122,460	122,460	287,556	174,306	230,931	108,471	1:0.430	1:0.703	1:0.530
P+A	3.0+3.0	2096.3^{a}	506.8^{c}	126,680	126,680	126,680	251,556	111,496	181,526	546,846	1:0.504	1:0.136	1:0.697
M+A	1.0+2.0	1999.9^{a}	253.4^{c}	116,830	116,830	116,830	239,988	55,748	147,886	31,056	1:0.487	1:2.096	1:0.790
M+A	2.0+2.5	1862.9^{a}	481.8^{c}	119,420	119,420	119,420	223,584	105,996	164,790	45,370	1:0.534	1:1.126	1:0.725
M+A	3.0+3.0	2258.5^{a}	450.1^{c}	121,987	121,987	121,987	259,104	99,022	179,063	57,076	1:0.471	1:1.232	1:0.681
P+A+one SHW[2] @ 6 WAS	1.0+2.0	2258.5^{a}	1831.9^{b}	125,500	125,500	125,500	271,020	403,018	337,020	211,520	1:0.463	1:0.311	1:0.372
M+A+one SHW @ 6WAS	1.0+2.0	2814.8^{a}	1956.6^{b}	124,830	124,830	124,830	337,776	430,452	384,114	259,284	1:0.370	1:0.290	1:0.324
Weeding @ 3&6 WAS	-	2537.0^{a}	3028.3^{a}	127,300	127,300	127,300	304,440	666,336	485,388	358,088	1:0.418	1:0.191	1:0.261
weedycheck	-	695.9^{b}	591.2^{c}	107,300	107,300	107,300	81,108	130,064	105,586	1,714	0:1.123	1:0.825	1:1.016

Calculation of total revenue is based on 120 kg^{-1} in 2015 and 220 kg^{-1} in 2016.;P+A = Pendimethalin + Atrazine; M+A = Metrolachlor + Atrazine WAS = Weeds After Sowing; 1 = Means in a column followed by the same alphabet (s) are not significantly different at 5% level of probably using Duncan's Multiple Range Test (DMRT).; SHW= Supplementary hoe weeding

at 2.0 +2.5 kg a.i. ha^{-1} had the highest cost-benefit ratio (1: 1.323) and (1:0.534) respectively, while the lowest cost-benefit ratio was from the plot treated with pre-emergence application of metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS in 2015. However, in 2016 two hand weedings at 3 and 6 WAS resulted in the lowest cost-benefit ratio (1:0.191) and (1:0.261), closely followed by metolachlor + atrazine and pendimethalin + atrazine at 1.0 +2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS. (1:0.290, 1:0.324, 1:0.311, 1:0.372) respectively. The highest cost-benefit ratio came from the plot treated with metolachlor + atrazine at 1.0 + 2.0 kg a.i. ha^{-1} (1:2.096 and 1:0.790), metolachlor + atrazine at 3.0+3.0 kg a.i. ha^{-1} (1:.1.123 and 1.0.681), pendimethalin + atrazine at 3.0+3.0 kg a.i. ha^{-1} (1:1.136 and 1:0.697) and the weedy check (1:0.825 and 1:1.016). Metolachlor + atrazine at 1.0+2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS had the lowest cost-benefit ratio followed by two hand weedings at 3 and 6 WAS in 2015. This is an indication that the aforementioned method of weed control is more beneficial financially than manual weeding and other treatments This is in line with the findings of Nazeer et al. (2004) who recommended Buctril-M herbicide over hoe weeding for the management of broadleaf weeds in wheat as a result of the ability of herbicide to produce higher grain yield compared with hoe weeding and the attractive benefit-cost ratio. However, in 2016, hand weeding at 3 and 6 WAS, followed by metolachlor + atrazine and pendimethalin + atrazine at 1.0+2.0 kg a.i. ha^{-1} gave the lowest cost- benefit ratio. Despite the good performance of two hand weedings, it is considered to be very strenuous and associated with a lot of drudgery. Therefore, metolachlor + atrazine and pendimethalin +atrazine at 1.0 + 2.0 kg a.i. ha^{-1} integrated with a SHW at 6 WAS may serve as a suitable alternative to two hand weedings.

It can therefore be concluded that metolachlor + atrazine and pendimethalin + atrazine at 1.0+2.0 kg a.i. ha^{-1} plus one SHW at 6 WAS can serve as alternatives to two hand weedings at 3 and 6 WAS for effective weed control and the promotion of higher yield and economic returns in the production of maize in the southern Guinea savanna of Nigeria.

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