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Evaluation of herbicide mixtures and manual weed control method 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, metolachlor + atrazine at 2.0 + 2.5 kg a.i./ha, metolachlor + atrazine at 3.0 + 3.0 kg a.i./ha, pendimethlin + atrazine at 1.0 + 2.0 kg a.i./ha, pendimethlin + atrazine at 2.0 + 2.5 kg a.i./ha, pendimethlin + atrazine at 3.0 + 3.0 kg a.i./ha, metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS) and pendimethlin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS, hand weeding at 3 and 6 WAS and a weedy check. These treatments were laid out in randomized complete block design with three replicates. Results showed that metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS significantly reduced weed infestation and gave higher maize grain yield and economic returns. These methods are therefore recommended to farmers as alternative to two hand weeding at 3 and 6 WAS.

Subjects: Environment & Agriculture; Bioscience; Environmental Studies & Management

Keywords: chemical weed control; hand weeding; weed infestation; maize; productivity

ABOUT THE AUTHOR

The author's name is E.O. Imoloame. He is a senior lecturer and a weed scientist in the Department of Crop Production, College of Agriculture, Kwara State University, Malete, Kwara State, Nigeria. His research area is Weed management in crops. He has done a lot of work on weed management in Nigeria and he is an advocate of Integrated Weed Management as the most effective and efficient solution to all weed problems. He has also conducted some research in weed ecology, economics and extension. He has plans to carry out research on the use of plant parts with allelopathic potentials to control weeds. This research report will be useful to Africans, Asians and South Americans and the tropical countries in the world that are still using manual weed control methods for weed control in maize.

PUBLIC INTEREST STATEMENT

My research seeks to find a method of weed control that can serve as an alternative to two hoe weeding at 3 and 6 weeks after planting which will significantly reduce weeds and promote higher maize yield. The manual weeding is very strenuous, unreliable, expensive and causes drudgery. These, de-motivate most of the youth population from venturing into farming which has been left for the aged and unproductive population of Nigeria.

The result of this research has revealed that a herbicide mixture of metolachlor and atrazine at 1.0 + 2.0 kg active ingredient per one hectare integrated with a supplementary hoe weeding at 6 weeks after planting is a suitable alternative to two hoe weeding (manual weeding). The aforementioned herbicide mixture is not only environmentally friendly, but will reduce drudgery and give higher yield and economic returns to farmers.

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice (MINFAL, 2003). Currently more of this crop is produced annually than any other grain and is the most important cereal crop in sub-Saharan Africa and Latin America (IITA, 2012). Maize provides staple food to large number of human population in the world. In the developing countries it is a major source of income to many farmers (Tagne, Fenjic, & Sonna, 2008).

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

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 of between 60–80% have been attributed to uncontrolled weed infestation in maize (Lagoke, Adeosun, Elemo, Chude, & Shebayan, 1998) and this finding was confirmed by Imoloame and Omolaiye (2016), who reported 89% yield loss in maize 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 offer little hope for expanding the present farm size. Hoe weeding is labour intensive, expensive and strenuous. Also, labour availability to carry out hand weeding is uncertain, thus making timeliness of weeding difficult to attain. This has resulted in the loss of yield (Adigun & Lagoke, 2003). It is estimated that about 40–60% of production cost is spent on manual weeding (Remison, 1979) which is similar to the report of Ekeleme (2009) 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. The efficiency of chemical weed control in increasing the yield of maize and other crops and reducing labour cost in the tropics especially in Nigeria have been documented (Akobundu, 1987; Imoloame, 2014; Joshua & Oni, 2002; Ogungbile & Lagoke, 1986).

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 the 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 (Ganie, Singh, & Singh, 2014; Norsworthy et al., 2012; Vencill et al., 2012)

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 maize grain yield.

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

2. 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 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). The experiment consisted of 10 treatments as follows: Metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha, metolachlor + atrazine at 2.0+2.5 kg a.i./ha, metolachlor + atrazine at 3.0 + 3.0 kg a.i./ha, pendimethlin + atrazine at 1.0+2.0 kg a.i./ha, pendimethlin + atrazine at 2.0 + 2.5 kg a.i./ha, pendimethlin + atrazine at 3.0 + 3.0 kg a.i./ha, metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS) and pendimethlin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 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 that was used was SUWAN-1-SR which was sown on the 11th and 14th of July, 2015 and2016 respectively. The crop was spaced at 75 cm × 25 cm to give a plant population of 53,333/ha. 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 l/ha. Karate insecticide containing 2.5% lamdacyhalothrin as active ingredient was applied at the rate of 30 ml in 10 l of water three times beginning from 6 WAS, to control army worm. Fertilizer was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg k_2O. These were provided with a compound fertilizer 15:15:15. Harvesting of maize was done on a net plot of 9 m^2 after the row at the edges at both sides of the plots were discarded to reduce error. The parameters measured included the following:

2.1. Weed density

This was determined at 6 and 12 WAS, by counting the total number of weed species per unit area (quadrat) in each plot.

2.1.1. Weed cover score

This was visually assessed at 6 and 12 WAS using a scale of 1–10, where 1 represented no weed cover and 10 complete weed cover.

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

Soil properties	
Physical properties	
Sand (g/kg)	812
Silt (g/kg)	94.0
Clay (g/kg)	94.0
Textural class	Loamy sand
Chemical properties	
PH in water (1:2.5)	6.2
Total organic carbon (g/kg)	13.2
Total nitrogen (g/kg)	1.4
Available P mg/kg	6.6
Exchangeable cation (C/mol/kg)	
K	0.17
Mg	2.23
Ca	1.4
Exch. micro nutrients (CmoL kg^{-1})	
Mn	184.0
Fe	82.0
Cu	1.68
Zn	1.92
Na	0.18

2.2. Weed dry weight (kg/ha)

This was obtained by taking weed samples at random from a 1 m^2 quadrat placed randomly in 3 locations in each plot at 6 and 12 WAS. The weeds were gathered together and put in a polythene bag and later oven-dried at a temperate of 80°C for 2 days to a constant weight. The oven-dried weight in gramme was converted to kilograme/ha for each plot.

2.3. Relative importance value

The Relative importance value (RIV%) of each species infesting the experimental plots was determined after the weeds were collected from the quadrat and before they were oven dried. The RIV was computed as the mean of the percentage of relative frequency and relative density for each species as indicated in the formula below (Wentworth, Conn, Skroch, & Mrozek, 1984).

$$\mathrm{RIV} = \frac{\mathrm{RD} \pm \mathrm{RF}}{2}$$

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 individual 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).

2.4. Plant height

This was determined by measuring the height of 5 randomly selected plant per plot at 6, 9 and 12 WAS, using a meter rule from the soil level to the apical bud of the plant.

2.4.1. Leaf area (cm^2)

The leaf area was determined at 9 and 12 WAS by measuring the length and breath of the top, middle and bottom leaves of five randomly selected plants from each plot and the average of these measurements was multiplied by a factor 0.75 to give the leaf area/plant (Moll & Kamprath, 1977).

2.5. Grain yield

This was determined by weighing the grains harvested from each net plot which was converted to kilograms per hectare using the formula below:

$$\text{Grain yield kg/ha} = \frac{\text{Grain yield/Net plot} \times 10,000}{\text{Net plot}\,(\mathrm{m}^2)}$$

2.6. Data analysis

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

2.7. Economic analysis

Information on the cost of all the cultural practices from land preparation to harvesting and processing was collected from Kwara State Agricultural Development Programme (KWASADP), Ilorin, an agency responsible for extension services in Kwara State, Nigeria. The price of 1 kilograme of maize was obtained from the open market to calculate the income/total revenue. The economic analysis was carried out using partial budgeting (Okoruwa, Obadaki, & Ibrahim, 2005) to calculate the gross marging (profit) as follows:

$$\mathrm{GM} = \mathrm{TR} - \mathrm{VC}$$

$$\mathrm{TR} = (\mathrm{Ys} \times \mathrm{Ps})$$

$$\mathrm{VC} = M + L$$

where GM = Gross margin/ ha for each treatment; TR = Total revenue, Naira/ha for each treatment; VC = Variable cost, Naira/ha for each treatment; Ys = maize grain yield (kg// ha) for each treatment; Ps = Price of maize per kg; *M* = Value of material input (seeds, fertilizer, insecticide, herbicides); *L* = Value of Labour (land preparation, planting, insecticide and herbicide, fertilizer application, harvesting, processing and packaging).

3. Results

3.1. Rainfall

The total amount of rainfall recorded in 2015 was 1,010.5 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 (Figure 1).

3.2. 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 WAS in 2015. This weed species, followed by *Rottboellia cochinchinensis* and *Mariscus alternifolius* in the descending order were the most prominent under pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha. A total of 7 weed species were recorded under this treatment at 6 WAS. This increased to 11 including *Paspalum scrobiculatum*, *Setaria barbata*, *Hyptis suaveolens* and *Commelina benghalensis* in the descending order as the most prominent at 12 WAS (Table 3). At higher application rates of pendimethalin + atrazine, *Paspalum scrobiculatum* and *Maniscus alternifolius* were the most prominent and important weed species growing in maize plot at 6 WAS. However at 12 WAS other weed species emerged, the most prominent among them were *Kyllinga erecta*, *Paspalum scrobiculatum, Hyptis suaveolens* and *Cyperus esculentus* in the descending order in the plots treated with pendimethalin + atrazine at 2.0 + 2.5 kg a.i./ha and *Kyllinga erecta Paspahum scrobiculatum* and *Commehlina benghalesis* under pendimethalin + atrazine at 3.0 + 3.0 kg a.i./ha. The total number of weed species under these treatments increased from 6 and 9 at 6 WAS (Table 2) to 8 and 10 respectively at 12 WAS (Table 3).

The most dominant weed species under metolachlor + atrazine at all the rates were *Paspalum scrobiculatum*, *Setaria barbata* and *Rottboellia cochinchinensis* at 6 WAS, while at 12 WAS, *Paspalum scrobiculatum* and *Setaria barbata* maintained their dominance across these treatments. Other weed species that were predominant under metolachlor + atrazine at 1.0 + 2.0 and 2.0 + 2.5 kg a.i./ha included *Digitaria horizontalis* and *Gomphrena celosoides* and *Hyptis suaveolens* under

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

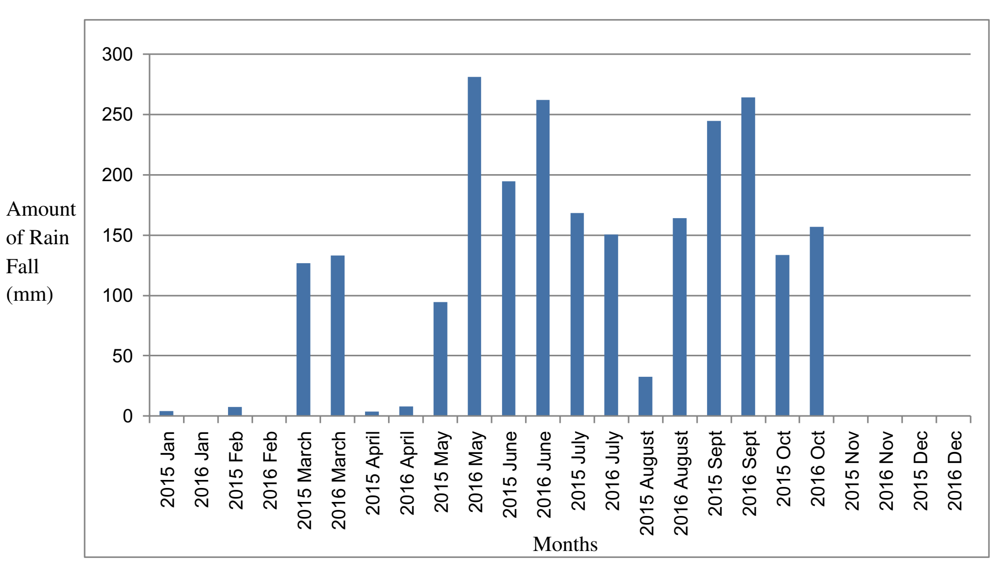

Table 2. Relative importance value index (RIV) of weed species at the experimental site at 6WAS, 2015

Weed species	Treatment										
	P+A 1.0+2.0	P+A 2.0+2.5	P+A 3.0+3.0	M+A 1.0+1.0	M+A 2.0+2.5	M+A 3.0+3.0	P+A+oneSHW @6WAS1.0+2.0	M+A+oneSHW @6WAS1.0+2.0	3&6 WAS	Weedy check	Over all 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
Kilinga squamatulata		5.4					7.5		8.5	2.9	2.4
Cyperus esculentus	6.1										0.6
Broadleaf											
Gonphrena 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
Agyratum conizoides			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	

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

Weed species	Treatment										
	P+A	P+A	P+A	M+A	M+A	M+A	P+A+oneSHW	M+A+oneSHW	3&6	Weedy check	Over all
	1.0+2.0	2.0+2.5	3.0+3.0	1.0+2.0	2.0+2.5	3.0+3.0	@6WAS1.0+2.0	@6WAS1.0+2.0	WAS		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
Setaria pumila	4.9										0.5
Mariscus alternifolius		3.9								2.3	0.62
Dactyloctenium aegyptium				2.9						4.1	0.7
Brachiaria alata										1.7	0.2
Sedges											
Cyperus iria	2.5								2.7	1.7	1.2
Cyperus rotundus										2.1	0.21
Pycreus lanceolatum				2.9							0.3
Kyllinga squmatulata								3.7			0.4
Cyperus esculentus	6.7	11	7.8	5.8			12.6	5.7	7.4	7.4	6.4
Cyperus difformis									2.7	1.7	0.3
Kyllinga erecta		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	

metolachlor + atrazine at 3.0 + 3.0 (Table 3). Also there was an increase in the number of weed species infesting the maize at 12WAS (Table 3). The weed species that were most prominent under the plot treated with pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6WAS were *Paspalum, scrobiculatum*, and *Vernonia galamensis* at 6 WAS. However at 12 WAS *Paspalum scrobiculatum, Vernonia galamensis* and *Cyperus rotundus* were more prominent. *Paspalum, scrobiculatum, Setaria barbata* and *Digitaria horizontalis* were the most prevalent weeds species under metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha + one SHW at 6 WAS, however at 12 WAS, the dominant weeds were *Paspalum scrobiculatum*, *Gomphrena celosiodes* and *hyptis suaveolens* (Table 3).

Paspalum scrobiculatum, Pycreus lanceolatus and *Chloris pilosa* were the most important weed species under two hand weeding at 6 WAS, however at 12 WAS, *Paspalum scrobiculatum* and *Setaria barbata* were predominant. Under the weedy plot, the most important weeds were *Paspalum scrobiculatum Ludwigia decurrens*, *Pycreus lanceolatus* and *Mariscus alternifolius*, however at 12 WAS, *Setaria barbata*, *Digitaria horizontalis* and *Paspalum scrobiculatum* constituted the most dominant weeds (Table 3).

At 6 WAS, *Paspalum scrobiculatum* was the most dominant weeds across the treatments followed by *Mariscus altenifoluis*, *Rottboelia cochinchinensis* and *Setaria barbata* in descending order (Table 2). However at 12 WAS, the same trend was recorded with *Paspalum scrobiculatum* occurring as the most dominant weeds followed by *Setaria barbata*, *Gomphrena celosoides* and *hyptis suaveolens*. (Table 3).

3.3. Effect of herbicide mixtures and manual weed control on weed dry matter and density in maize

Pre-emergence application of pendimethalin + atrazine and metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS caused a significant reduction in weed dry matter than the other methods of weed control, however, this effect was comparable to two hand weeding at 3 and 6 WAS and the other treatments at the mean, except weedy check which supported significantly higher weed dry matter (Table 4). Later in the season at 12 WAS, the two herbicide mixtures plus one SHW at 6 WAS and hand weeding at 3 and 6 WAS maintained significantly lower weed dry matter than the other treatments in both years and their mean (Table 4). Metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha 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).

3.4. Effect of herbicide mixtures and manual weed control method on the growth of maize

All the herbicide treatments increased plant height significantly than 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 and metolachlor + atrazine at 3.0 + 3.0 kg a.i./ha, which produced comparable taller plants at the mean (Table 6). Pre-emergence application of pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW resulted in leaf area significantly larger than the weedy check but was comparable to the other weed control methods including two hand weeding at 9 WAS (Table 7). However, pendimethalin + atrazine and metholachlor + atrazine at 1.0 + 2.0 plus one SHW, all the rates of metolachlor + atrazine and two hoe weeding gave significantly larger leaves in both years and their mean at 12 WAS.

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

Two hoe weeding 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 plus one SHW at 6 WAS, but was significantly higher than the rest of the treatments and the weedy check in both years and their means (Table 8).

Table 4. Effect of herbicide mixtures and manual weed control on weed dry matter (kg/ha)

Treatment	Rate kg a.i./ha	6WAS[1]			12 WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0 + 2.0	229.8 ± 100.919a[2]	1,647.3 ± 1,059.06b	938.6 ± 1,027.40ab	537.5 ± 57.83ab	2,199.8 ± 657.0bc	1,368.6 ± 1,001.0b
P+A	2.0 + 2.5	234.2 ± 50.80a	1,494.2 ± 664.40b	864.2 ± 808.62b	420.3 ± 289.44ab	1,899.8 ± 633.0bc	1,160.1 ± 908.0bc
P+A	3.0 + 3.0	112.5 ± 71.84a	696.5 ± 54.68bc	404.5 ± 324.89b	426.4 ± 302.65ab	2,177.8 ± 454.0bc	1,302.1 ± 1,019.0b
M+A	1.0 + 2.0	544.9 ± 715.28a	980.0 ± 640.24bc	762.4 ± 652.23b	284.6 ± 137.92b	2,288.9 ± 962.0bc	1,286.7 ± 1,258.0b
M+A	2.0 + 2.5	504.3 ± 412.43a	870.0 ± 96.02bc	687.1 ± 334.44b	469.2 ± 66.65ab	2,844.5 ± 239.0b	1,656.8 ± 1,318.0ab
M+A	3.0 + 3.0	124.4 ± 76.73a	1,228.0 ± 928.68bc	676.2 ± 884.21b	103.6 ± 108.95b	1,433.2 ± 1,530.0cd	1,768.4 ± 1,213.0bc
P+A+oneSHW @ 6 WAS	1.0 + 2.0	289.8 ± 245.91a	66.9 ± 46.22d	178.3 ± 199.86b	134.8 ± 34.78b	355.6 ± 271.0d	245.2 ± 211.0cd
M+A+oneSHW a@ 6WAS	1.0 + 2.0	155.9 ± 112.23a	185.3 ± 161.05d	170.6 ± 125.19b	163.9 ± 141.98b	233.3 ± 88.0d	198.6 ± 112.0d
Weeding @ 3&6 WAS	–	43.3 ± 18.07a	418.7 ± 312.59cd	231.9 ± 284.67b	261.5 ± 195.05b	344.5 ± 271.0d	302.9 ± 216.0cd
Weedy check	–	252.9 ± 139.68a	2,973.6 ± 338.56a	1,613.2 ± 1,508.07a	857.8 ± 684.19a	4,088.5 ± 605.0a	2,473.2 ± 1,861.0a

Notes: Data presented as means ± SD. P + A = Pendimethalin + Atrazine; M + A = Metolachlor + Atrazine; SHW = Supplementary hoe weeding; Means ± standard deviation.

[1]Weeks after sowing.

[2]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).

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

Treatment	Rate kg a.i./ha	Weed density/m²			Weed cover		
		12 WAS[1]			6 WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0 + 2.0	18.2 ± 11.38b	45.0 ± 9.62b[2]	31.6 ± 17.44b	4.3 ± 3.18b	5.7 ± 2.08bc	5.0 ± 2.51b
P+A	2.0 + 2.5	26.1 ± 11.53b	38.0 ± 12.52b	32.0 ± 12.61b	1.8 ± 0.29bc	4.7 ± 2.02bc	3. 3 ± 2.02bc
P+A	3.0 + 3.0	13.8 ± 6.58b	52.7 ± 13.89b	33.2 ± 23.43b	1.3 ± 0.17c	4.2 ± 2.25bc	2.7 ± 2.12bc
M+A	1.0 + 2.0	17.2 ± 5.08b	26.0 ± 10.57b	21.6 ± 8.83b	1.5 ± 0.50c	7.7 ± 1.52ab	4.6 ± 3.53bc
M+A	2.0 + 2.5	30.1 ± 5.69b	32.8 ± 4.78b	31.5 ± 4.92b	1.8 ± 0.58bc	7.0 ± 2.65ab	4.4 ± 3.31bc
M+A	3.0 + 3.0	21.5 ± 17.17b	41.2 ± 28.86b	31.4 ± 23.84b	1.1 ± 0.12c	6.5 ± 3.50ab	3.8 ± 3.68bc
P+A+oneSHW @ 6 WAS	1.0 + 2.0	10.2 ± 6.51b	12.2 ± 2.83b	11.2 ± 4.62b	3.3 ± 0.11bc	1.3 ± 0.58d	2.3 ± 1.89bc
M+A+oneSHW @ 6WAS	1.0 + 2.0	15.1 ± 10.70b	16.5 ± 5.72b	15.8 ± 7.71b	2.7 ± 2.36bc	1.3 ± 0.58d	2.1 ± 1.73c
Weeding @ 3&6 WAS	–	14.6 ± 5.54b	20.6 ± 7.64b	17.6 ± 6.80b	1.1 ± 2.49c	2.3 ± 1.52cd	1.7 ± 1.17c
Weedy check	–	45.7 ± 15.19a	147.6 ± 92.50a	142.2 ± 189.79a	10.0 ± 0.12a	10.0 ± 0.0a	10.0 ± 0.0a

Notes: Data presented as means ± SD. P + A = Pendimethalin + Atrazine; M + A = Metolachlor + Atrazine; SHW = Supplementary hoe weeding; Means ± standard deviation.

[1]Weeks after sowing.

[2]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).

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

Treatment	Rate kg a.i./ha	Plant height (cm)					
		6 WAS[1]			12WAS		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0 + 2.0	63.3 ± 12.5a	66.5 ± 8.12ab	64.9 ± 9.60ab	186.3 ± 12.93a	159.1 ± 4.30b	172.7 ± 17.24bc[2]
P+A	2.0 + 2.5	71.5 ± 3.16a	68.4 ± 6.30ab	69.9 ± 4.76a	173.6 ± 28.76a	158.2 ± 6.44b	165.8 ± 20.57bc
P+A	3.0 + 3.0	58.5 ± 3.26a	61.9 ± 5.10ab	60.2 ± 4.26ab	180.9 ± 27.13a	146.2 ± 25.36b	163.6 ± 30.18bc
M+A	1.0 + 2.0	56.1 ± 4.92a	57.9 ± 5.94bc	57.0 ± 4.97bc	193.3 ± 6.43a	147.5 ± 30.82b	170.4 ± 32.03bc
M+A	2.0 + 2.5	61.3 ± 10.07a	64.8 ± 5.02ab	63.0 ± 7.38ab	201.3 ± 23.39a	146.2 ± 14.80b	173.7 ± 34.87bc
M+A	3.0 + 3.0	56.8 ± 9.09a	65.1 ± 15.85ab	60.9 ± 12.41ab	200.9 ± 12.70a	148.7 ± 7.37b	174.8 ± 30.10ab
P+A+oneSHW @6 WAS	1.0 + 2.0	57.7 ± 6.41a	77.0 ± 20.13a	67.4 ± 17.03ab	186.0 ± 6.39a	172.5 ± 46.24b	179.2 ± 30.44ab
M+A+oneSHW @ 6WAS	1.0 + 2.0	63.3 ± 5.53a	68.9 ± 7.30ab	65.3 ± 7.31ab	203.9 ± 5.52a	176.3 ± 44.65b	190.1 ± 32.22ab
Weeding @ 3&6 WAS	–	59.3 ± 17.87a	76.1 ± 7.35ab	67.7 ± 15.28ab	190.2 ± 28.03a	217.1 ± 12.1a	203.7 ± 24.26a
Weedy check	–	50.8 ± 2.64a	54.1 ± 1.80c	52.5 ± 2.70c	165.3 ± 21.55a	148.6 ± 32.8b	156.9 ± 26.47c

Notes: Data presented as means ± SD. P + A = Pendimethalin + Atrazine; M + A = Metolachlor + Atrazine; SHW = Supplementary hoe weeding; Means ± standard deviation.

[1]Weeks after sowing.

[2]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).

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

Treatment	Rate kg a.i./ha	Leaf area (cm^2)					
		9 WAS			12 WAS[1]		
		2015	2016	Mean	2015	2016	Mean
P+A	1.0 + 2.0	401.4 ± 72.34a[2]	200.3 ± 39.15ab	300.8 ± 121.80a	324.4 ± 24.12bc	219.5 ± 80.10b	271.9 ± 78.48ab
P+A	2.0 + 2.5	364.4 ± 21.74ab	218.9 ± 82.13ab	291.7 ± 96.12a	281.2 ± 23.72bc	273.3 ± 50.10b	277.3 ± 35.55ab
P+A	3.0 + 3.0	378.0 ± 32.78ab	218.5 ± 58.39ab	298.3 ± 97.12a	325.4 ± 18.27bc	278.6 ± 27.07b	302.0 ± 32.90ab
M+A	1.0 + 2.0	325.2 ± 14.27ab	200.1 ± 65.14ab	262.7 ± 80.44a	341.7 ± 14.27ab	258.1 ± 68.41b	299.9 ± 70.88ab
M+A	2.0 + 2.5	326.2 ± 20.06ab	200.9 ± 63.38ab	263.6 ± 80.48a	340.2 ± 20.06ab	270.1 ± 108.63b	305.1 ± 84.31a
M+A	3.0 + 3.0	334.3 ± 38.03ab	176.2 ± 20.40ab	255.2 ± 90.80a	395.9 ± 38.04a	267.6 ± 110.45b	331.8 ± 102.10a
P+A+oneSHW @ 6 WAS	1.0 + 2.0	393.5 ± 75.90a	244.4 ± 62.10a	318.9 ± 102.10a	276.1 ± 75.10bc	304.4 ± 119.40ab	290.3 ± 77.97a
M+A+oneSHW @6WAS	1.0 + 2.0	382.6 ± 38.10ab	230.1 ± 33.96ab	306.4 ± 89.53a	343.7 ± 38.10ab	282.9 ± 107.75b	313.3 ± 80.03a
Weeding @ 3&6 WAS	–	347.9 ± 47.44ab	199.6 ± 33.73ab	273.8 ± 834.40a	298.8 ± 47.44bc	395.5 ± 79.64a	347.1 ± 88.78a
Weedy check	–	300.3 ± 29.14b	149.6 ± 19.10b	224.9 ± 85.49a	255.0 ± 29.13c	201.4 ± 19.99b	228.2 ± 54.25b

Notes: Data presented as means ± SD. P + A = Pendimethalin + Atrazine; M + A = Metolachlor + Atrazine; SHW = Supplementary hoe weeding; Means ± standard deviation.

[1]Weeks after sowing.

[2]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).

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

Treatment	Rate kg a.i./ha	Grain yield (kg/ha)		
		2015	2016	Mean
P+A	1.0 + 2.0	2,333.3 ± 587.94a[2]	1,300.8 ± 702.30bc	1,817.1 ± 809.57bc
P+A	2.0 + 2.5	2,396.3 ± 721.48a	792.3 ± 330.28c	1,594.3 ± 1,011.80bc
P+A	3.0 + 3.0	2,096.3 ± 206.48a	506.8 ± 328.64c	1,301.5 ± 904.55cd
M+A	1.0 + 2.0	1,999.9 ± 968.66a	253.4 ± 102.00c	1,126.7 ± 1,137.84de
M+A	2.0 + 2.5	1,862.9 ± 483.82a	481.8 ± 294.24c	1,172.4 ± 837.00de
M+A	3.0 + 3.0	2,258.5 ± 789.20a	450.1 ± 244.32c	1,304.7 ± 1,072.10cd
P+A+oneSHW @ 6 WAS[1]	1.0 + 2.0	2,258.5 ± 64.9a	1,831.9 ± 706.76b	2,045.7 ± 506.05ab
M+A+oneSHW[3] @ 6WAS	1.0 + 2.0	2,814.8 ± 231.27a	1,956.6 ± 901.70b	2,385.7 ± 753.39ab
Weeding @ 3&6 WAS	–	2,537.0 ± 447.56a	3,028.3 ± 917.90a	2,782.7 ± 6.80a
Weedy check	–	695.9 ± 173.40b	591.2 ± 289.75c	633.6 ± 189.79e

Notes: Data presented as means ± SD. P + A = Pendimethalin + Atrazine; M + A = Metolachlor + Atrazine; SHW = Supplementary hoe weeding; Means ± standard deviation.

[1]Weeks after sowing.

[2]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).

[3]Supplementary hoe weeding (SHW) at 6 WAS which is combined with herbicide application for the control of weeds and also to reduce drudgery which is associated with two hoe weeding.

3.6. Economic assessment of the use of different methods of weed control

The highest grain yield of maize (2,814.8 kg/ha) was obtained from plots treated with pre-emergence application of metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS followed by pendimethalin + atrazine at 1.0 + 2.0 kg a.i.ha /ha plus one SHW at 6 WAS, while the least yield (1,862.9 kg/ha) was produced by metholachlor + atrazine at 2.0 + 2.5 kg a.i./ha in 2015 (Table 9). However in 2016 and the mean, hand weeding at 3 and 6 WAS resulted in the highest maize yield (3,028.3 and 2,782.7 kg/ha) followed by metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one supplementary hoe weeding at 6 WAS (1,956.6 and 2,385.7 kg/ha).

Hand weeding at 3 and 6 WAS was the most expensive method of weed control per hectare (₦127, 300.00/ha) among the treatments, while the lowest (₦107, 300.00) was from weedy plots in both years and their mean. In 2015, metolachlor + atrazine at 1.0 + 2.0 kg a.i. /ha 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 plus one SHW at 6 WAS generated the highest income (₦337,776.00) (₦304,440.00) and (₦271, 020.00)/ha respectively, while weedy check resulted in the lowest income (₦81,108.00). However in 2016 and the mean, higher income was obtained from two hand weeding at 3 and 6 WAS (₦666,336.00) and (₦485,388.00)/ha respectively, followed by metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS (₦430,452.00) and (₦384,114.00). The lowest revenue was got from metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha (₦55,784) and (₦147,886)/ha.

The highest gross margin/profit (₦358,088.00)/ha 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 plus one SHW at 6 WAS (₦259,284.00)/ha, while the lowest profit/gross margin(₦–1,714.00)/ha was recorded for weedy check and metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha (₦31,056.00) (Table 9).

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	Grain yield kg/ha		Cost of production (N)		Mean	Total revenue (N)		Mean	Gross margin (N)
		2015	2016	2015	2016		2015	2016		
P+A	1.0 + 2.0	2,333.3a[1]	1,300.8bc	117,500	117,500	117,500	279,996	286,176	283,086	165,586
P+A	2.0 + 2.5	2,396.3a	792.3c	122,460	122,460	122,460	287,556	174,306	230,931	108,471
P+A	3.0 + 3.0	2,096.3a	506.8c	126,680	126,680	126,680	251,556	111,496	181,526	546,846
M+A	1.0 + 2.0	1,999.9a	253.4c	116,830	116,830	116,830	239,988	55,748	147,886	31,056
M+A	2.0 + 2.5	1,862.9a	481.8c	119,420	119,420	119,420	223,584	105,996	164,790	45,370
M+A	3.0 + 3.0	2,258.5a	450.1c	121,987	121,987	121,987	259,104	99,022	179,063	57,076
P+A+oneSHW[2] @ 6 WAS	1.0 + 2.0	2,258.5a	1,831.9b	125,500	125,500	125,500	271,020	403,018	337,020	211,520
M+A+oneSHW @ 6WAS	1.0 + 2.0	2,814.8a	1,956.6b	124,830	124,830	124,830	337,776	430,452	384,114	259,284
Weeding @ 3&6 WAS	–	2,537.0a	3,028.3a	127,300	127,300	127,300	304,440	666,336	485,388	358,088
Weedy check	–	695.9b	591.2c	107,300	107,300	107,300	81,108	130,064	105,586	1,714

Notes: Calculation of total revenue is based on ₦120/kg in 2015 and ₦220/kg in 2016.

P + A = Pendimethalin + Atrazine; M + A = Metrolachlor + Atrazine; WAS = Weeds After Sowing; SHW = Supplementary hoe weeding.

[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).

4. Discussion

4.1. Effect of herbicide mixtures and manual weeding on relative importance value

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 were 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*. Since grass weeds have been reported to be more competitive and damaging in grass crops (Anonymous, 2007) 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, Sement, and Fontenay (1980) reported that 60–75% of total grassy weeds as against only 30–35% broadleaved weeds emerged during first 15 days of an intensively cultivated field in Ivory Coast.

4.2. Effect of herbicide mixtures and manual weed control method on weed infestation

The ability of metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW 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 with one supplementary hoe weeding have been found to be very effective in the control of weeds and promoting higher yields in various crops (Imoloame, 2014; Peer et al., 2013; Veeramani, Palchamy, Ramasamy, & Rangaraju, 2001).

4.3. Effect of herbicide mixtures and manual weed control method on the growth of maize

Two hand weeding 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. This was probably due to their ability to significantly reduce weed infestation than the other treatments which could have minimized weed competition and made sufficient growth resources (moisture, plant nutrients, light) available for utilization and better performance by maize crop. Also, the larger leaf area of the maize plants produced from plots treated with metolachlor + atrazine and pendimethalin + atrazine plus one SHW 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 confer advantage to maize as it provides a larger surface for the capture of more solar radiation for increased photosynthesis and higher yield.

4.4. Effect of herbicide mixtures and manual weeding on grain yield

Higher maize grain yield was produced by metolaclor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS and two hand weeding at 3 and 6 WAS compared to the other weed control methods probably as a result of better weed control provided by these treatments which gave rise to better growth, development and higher grain yields. The weedy check gave significantly lower yields due to the promotion of significantly higher weed dry matter, weed density and weed cover which led to more intense weed competition for sunlight moisture and plant nutrient which resulted in lower grain yield. This result is similar to that of Imoloame (2014) and Veeramani et al. (2001), who reported increase in grain yield as a result of the use of herbicide application plus one SHW.

4.5. Economic assessment of the use of herbicide mixtures and manual weeding on weed infestation

Hand weeding at 3 and 6 WAS was the most expensive weed control method in both years and the mean. This result is corroborated by the findings of Imoloame, Joshua, and Gworgwor (2010), Imoloame (2014), Adigun and Lagoke (2003) that manual weeding is very expensive. While metolachlor + atrazine at 1.0 + 2.0 kg a.i./ha 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 and the mean, two hoe weeding produced the highest grain yield and therefore gave higher revenue. Hand weeding at 3 and 6 WAS gave the highest profit/gross margin/ha followed by metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS. Despite this result, manual weeding is considered to be very strenuous and causes a lot of drudgery and therefore metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS could be a suitable alternative to two hand weeding.

It can therefore be concluded that metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS can serve as alternative to two hand weeding at 3 and 6 WAS for effective weed control and the promotion of higher yields in maize and economic returns in the Southern Guinea Savanna of Nigeria.

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