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, pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha, pendimethalin + atrazine at 2.0 + 2.5 kg a.i./ha, pendimethalin + 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 pendimethalin + 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 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

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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, demotivate 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 and 2016 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<Psub>2</sub>O<Psub>5</sub> and 60 kg k₂O. These were provided with a compound fertilizer 15:15:15. Harvesting of maize was done on a net plot of 9 m² 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.

| Soil properties | Physical properties | 2015 |
|-----------------|---------------------|------|
| 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 m² 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 temperature of 80°C for 2 days to a constant weight. The oven-dried weight in gramme was converted to kilogramme/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).

\[
\text{RIV} = \frac{\text{RD} \pm \text{RF}}{2}
\]

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 (cm²)**

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:

\[
\text{Grain yield kg/ha} = \frac{\text{Grain yield/Net plot} \times 10,000}{\text{Net plot (m²)}}
\]

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 kilogramme 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 margin (profit) as follows:

\[
\text{GM} = \text{TR} - \text{VC}
\]

\[
\text{TR} = (Ys \times Ps)
\]

\[
\text{VC} = M + L
\]
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 *Maniscus 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* and *Paspalum scrobiculatum* and *Commelina benghalensis* 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 3) 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.](image-url)
| 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+1.0 | 2.0+2.5 | 3.0+3.0 | @6WAS1.0+2.0 | @6WAS1.0+2.0 | WAS | 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 | 12.6 | 12.5 | 12.5       | 12.5       | 3.6  | 3.6         | 4.1      |
| Setaria barbata             |           | 7.5  | 15   | 11.4 | 11.2 | 11.2 | 11.2 | 31.5       | 31.5       | 7.0  | 7.0         | 8.4      |
| Rottboellia cochinchinensis |           | 10.9 | 12   | 26.9 | 38.6 | 38.6 | 38.6 | 38.6       | 38.6       | 8.8  | 8.8         |          |
| Chloris pilosa              |           |      |     |     |     |     |     |            |            | 10   | 10          |          |
| **Sedges**                  |           |       |     |     |     |     |     |            |            |     |             |          |
| Mariscus alternifolius      |           | 10.7 | 29.2 | 11.8 | 13.2 | 7.5  | 8.5  | 8.5        | 8.5        | 10.4 | 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  | 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      |
| Agryatum canzoides          |           | 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          |          |
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 | 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|     |     |     |     |            |            |     |     |     |
| *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 |
| *Setaria pumila*                  |                         | 4.9 |     |     |     |     |     |            |            |     | 0.5 |     |
| *Mariscus alternifolius*          |                         | 3.9 |     |     |     |     |     |            |            |     | 2.3 | 0.62|
| *Dactylactenium aegyptium*        |                         |     |     |     |     |     |     |            |            |     |     |     |
| *Brachiaria alata*                |                         |     |     |     |     |     |     |            |            |     |     |     |
| **Sedges**                        |                         |     |     |     |     |     |     |            |            |     |     |     |
| *Cyperus iria*                    |                         | 2.5 |     |     |     |     |     |            |            |     | 1.7 | 1.2 |
| *Cyperus rotundus*                |                         |     |     |     |     |     |     |            |            |     | 2.1 | 0.21|
| *Pycreus lanceolatum*             |                         |     |     |     |     |     |     |            |            |     | 0.3 |     |
| *Kyllinga squamatulata*           |                         |     |     |     |     |     |     |            |            |     | 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 |
| *Kyllinga erecta*                 |                         | 17  | 19.3|     |     |     |     |            |            |     | 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 suaveolus*                |                         | 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 |     |     |     |     |     |            |            |     |     | 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|     |     |     |            |            |     | 4.0 |     |
| *Hyptis lanceolata*               |                         |     |     |     |     |     |     |            |            |     |     | 1.3 |
| *Portulaca Oleracea*              |                         |     |     |     |     |     |     |            |            |     |     |     |
| **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 celosoides 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 Ludwiga 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 alternifolius, 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  |
|----------------------------------|----------------|------------|--------|-------|-------|-------|-------|-------|-------|
|                                  |                | 2015       | 2016   | Mean  | 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 ± 1,027.40db | 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 ± 1,530.00cd | 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 @ 6 WAS                | 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 ± 312.59a | 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.
1Weeks after sowing.
2Means 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).
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 |
|-----------|----------------|-----------------|------------|
|           |                | 2015            | 2016       | Mean      | 2015      | 2016       | Mean      |
| P+A       | 1.0 + 2.0      | 18.2 ± 11.38b   | 2015       | 4.5 ± 0.962b² | 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   | 2016       | 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    | Mean       | 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    | 2015       | 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    | 2016       | 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   | Mean       | 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    | 2015       | 12.2 ± 2.83b  | 11.2 ± 4.62b  | 3.3 ± 0.11bc | 1.3 ± 0.58d | 2.3 ± 1.89bc |
| M+A+oneSHW @6 WAS | 1.0 + 2.0     | 15.1 ± 10.70b   | 2016       | 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    | 2016       | 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   | 2015       | 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.

1Weeks after sowing.

2Means 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 6. Effect of herbicide mixtures and manual weed control on plant height

| Treatment                  | Rate kg a.i./ha | Plant height (cm) |               |               | Mean  |               |               |               |
|----------------------------|-----------------|-------------------|---------------|---------------|-------|---------------|---------------|---------------|
|                            |                 | 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 | 09 |
| P+A                       | 2.0 + 2.5       | 71.5 ± 3.16a     | 71.9 ± 6.30bc | 69.9 ± 4.76a  | 173.6 ± 28.76a | 158.2 ± 6.44b | 165.8 ± 20.57bc | 10 |
| 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 | 09 |
| 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 | 10 |
| M+A                       | 2.0 + 2.5       | 61.3 ± 10.07a    | 64.8 ± 5.02ab | 63.0 ± 7.38ab | 201.3 ± 23.93a | 146.2 ± 14.80b | 173.7 ± 34.87bc | 10 |
| M+A                       | 3.0 + 3.0       | 56.8 ± 9.09a     | 65.1 ± 15.8Sab| 60.9 ± 12.41ab| 200.9 ± 12.70a | 148.7 ± 7.37b  | 174.8 ± 30.10ab | 10 |
| 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 | 10 |
| 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 | 10 |
| 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  | 10 |
| 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  | 10 |

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

| Treatment                | Rate kg a.i./ha | Leaf area (cm²) |          |          |          |          |          |
|--------------------------|-----------------|-----------------|----------|----------|----------|----------|----------|
|                          |                 | 9 WAS           | 2015     | 2016     | Mean     | 2015     | 2016     | Mean     |
|                          |                 |                 |          |          |          |          |          |
| P+A                      | 1.0 + 2.0       | 401.4 ± 72.3a²  | 200.3 ± 39.15ab | 300.8 ± 121.80a | 324.4 ± 24.12bc | 219.5 ± 80.10b | 271.9 ± 78.48ab |
|                          | 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 |
|                          | 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 |
|                          | 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 |
|                          | 3.0 + 3.0       | 334.3 ± 38.03ab | 176.2 ± 20.40ab | 255.2 ± 90.80a | 395.9 ± 38.04a | 267.6 ± 110.45b | 313.8 ± 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        | -               | 34.79 ± 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.

1Weeks after sowing.

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

| Treatment | Rate kg a.i./ha | 2015 | 2016 | Mean |
|-----------|----------------|------|------|------|
| P+A | 1.0 + 2.0 | 2,333.3 ± 587.94a | 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 WAS1 | 1.0 + 2.0 | 2,258.5 ± 64.9a | 1,831.9 ± 706.76b | 2,045.7 ± 506.05ab |
| M+A+oneSHW2 @ 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.

1Weeks after sowing.
2Means 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).
3Supplementary 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.
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          | 1,300.8bc              | 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         | 287,556 | 174,306          | 230,931 | 108,471 |
| P+A       | 3.0 + 3.0      | 2,096.3a          | 506.8c                 | 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         | 239,988 | 55,748           | 147,886 | 31,056  |
| M+A       | 2.0 + 2.5      | 1,862.9a          | 481.8c                 | 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         | 259,104 | 99,022           | 179,063 | 57,076  |
| P+A+oneSHW\(^{6}\) @ 6 WAS | 1.0 + 2.0 | 2,258.5a | 1,831.9b | 125,500 | 125,500 | 271,020 | 403,018 | 337,020 | 211,520 |
| M+A+oneSHW @ 6 WAS | 1.0 + 2.0 | 2,814.8a | 1,956.6b | 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 | 304,440 | 666,336 | 485,388 | 358,088 |
| Weedy check | – | 695.9b | 591.2c | 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.

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 scrobiculatum 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 metolachlor + 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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References
Adigun, J. A., & Lagoke, S. T. O. (2003). Weed control in transplanted rainfed and integrated tomato in the Nigerian Savanna. Nigerian Journal of weed Science, 16, 23–29.
Akobundu, I. O. (Ed.). (1987). Weed science in the tropics. In Principles and practices (522 pp.). New York: John Wiley and Sons.
Anonymous. (2007). Agronomy guide 2007–2008. University Park: Penn State College of Agricultural Science. Retrieved from https://agguide.agronomy.psu.edu/pm/sec1/sec2f.cfm
Das, T. K. (2011). Weed science basics and applications (907 pp.). New Delhi: Jain Brothers.
Deat, M., Sement, G., & Fontenay, P. (1980). Role of preceeding crop on weed infestation of cotton in a crop rotation system. In I. O. Akobundu (Ed.), Weed and their control in the humid and subhumid tropics (pp. 305–311). Ibadan: International Institute of Tropical Agriculture. Proceedings Series 3.
Ekedele, F. (2000). Major weeds of legumes and cereals and control measures. In H. A. Ajeigbe, T. Abduoulaye, & D. Chikoye (Eds.), Proceedings of the Training Workshop on Production of Legumes and Cereals Seeds on 24th January–10 February, 2008 at the International Institute of Tropical Agriculture, Kano Station, Kano, Nigeria (pp. 29–13).
FAO. (2011). Food and Agricultural Organization, FAOSTAT on crop production. Retrieved from www.fao.org/FAOSTAT
Ganie, Z. A., Singh, S., & Singh, S. (2014). Integrated weed management in dry-seeded rice. Indian Journal of weed science, 46, 172–173.
IITA. (2012). International Institute of Tropical Agriculture. Retrieved 12 July, 2013 from www.iita.org/maize
Imoloame, E. O. (2014). Economic evaluation of methods of weed control in soybeans (Glycine Max (L.) Meril) production in the southern Guinea savanna of Nigeria. Nigerian Journal of Experimented and Applied Biology, 14, 81–85.
Imoloame, E. O., Joshua, S. D., & Gworgwor, N. A. (2010). Evaluation of post-emergence herbicides for weed control in sesame (Sesame indium L.) in the Sudan Savanna zone of Nigeria. Nigerian Journal of weed Science, 23, 73–74.
Imoloame, E. O., & Omolaje, J. O. (2016). Impact of different periods of weed interference on the growth and yield of maize (Zea mays L.). Journal of Tropical Agriculture, 93, 245–257.
Joshua, S. D., & Oni, A. O. (2002). Economic evaluation of herbicide use in millet-cowpea intercrop in the Sudan Savanna zone of Nigeria. Journal of Agriculture, Science and Technology, 12, 15–21.
Lagoke, S. T. O., Adesoun, S. O., Elemo, K. A., Chude, V. O., & Shebayan, J. A. Y. (1998). Herbicide evaluation for the control of weeds in maize at Samaru. In Report on cereals research cropping scheme meeting held at DARI/ABU Samaru (pp. 90–91). Nigeria: Zaria.
MINFAL. (2003). Agricultural statistics of Pakistan, 2001–2002 (pp. 18–19). Islamabad: Ministry of Food, Agricultural and Livestock Economic Wing.
Moll, R. H., & Kamprath, E. J. (1977). Effect of population density on agronomic traits associated with genetic increases in yield of zea mays L. Agronomy Journal, 96, 81–84. https://doi.org/10.2134/agronj1977.00021962006900010021x
Norsworthy, J. K., Ward, S. M., Shaw, D. R., Llewellyn, R. S., Nichols, R. L., Webster, T. M., ... Witt, W. W. (2012). Reducing the risks of herbicide resistance. Best management practices and recommendations. Weed Science (Special Issue), 60, 31–62.
Ogunbile, A. O., & Lagoke, S. T. O. (1986). On farm evaluation of the economics of chemical weed control in oxen-mechanized maize production in Nigeria Savanna. Tropical Pest Management, 32, 373.
Okoruwa, V. O., Obadaki, F. O., & Ibrahim, G. (2005). Profitability of beef cattle fattening in the cosmopolitan Ccty of Ibadan, Oyo State. Moor Journal of Agricultural Research, 6, 45–51.

Peer, F. A. & Badrul lone B.A., Qayoom S., Ahmed L., Khanday B.A., Saising P., & Singh G. (2013). Effect of weed control methods on yield and yield attributes of Soyabean. African Journal of Agricultural Research, 8, 6135–6141.

Remison, S. U. (1979). Effect of weeding and nitrogen treatments on yield of maize in Nigeria. Weed Research, 19, 71–74.

Tagne A., Fenjic, T. P, & Sonna, C. (2008). Essential oil and plant extracts as potential substitutes to synthetic fungicides in the control of fungi. International Conference on Diversifying Crop Production, 12–15 October, La Grande – Motie, France.

Veeramani, A., Polchamy, A., Ramasamy, S., & Rangaraju, G. (2001). Integrated weed management in Soyabean (Glycine max (L.) Merril) under various plant densities. The Madras Agricultural Journal, 88, 451–456.

Vencill, W. K., Nichols, R. L., Webster, T. M., Soteres, J. K., Mallory-Smith, C., Burgos, N. R., … McClelland, M. R. (2012). Herbicide resistant: Towards an understanding of resistance development and the impact of herbicide resistant crops. Weed Science, 60, 1–3. https://doi.org/10.1614/0043-1745-60.1.1

Wentworth, T. R., Conn, J. S., & Skroch, W.A. and Mrozek, E. Jr. (1984). Gradient analysis and numerical classification of apple orchards and weed vegetation. Agriculture, Ecosystems & Environment, 11, 239–251. https://doi.org/10.1016/0167-8809(84)90033-1