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Comparative effect of weed control methods on Mexican sunflower (*Tithonia diversifolia*) in maize

Josephine Olutayo Amosun[1]*, Olubunmi Abiodun Aluko[1] and Donatus Obinna Ilem[2]

[1]Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, Ibadan, Oyo State, Nigeria.
[2]Horticulture Department, Federal University of Agriculture, Abeokuta, Nigeria.

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Mexican sunflower management in arable crops is becoming increasingly important due to its prevalent growth habit. The field experiments were conducted to compare weed suppressive abilities of two cover crops and two maize herbicides on Mexican sunflower. The treatments consist of the pre-emergence application of Primextra Gold (atrazine + metolachlor) at 4 l/ha, a post-emergence application of Aminoforce (2, 4-D) at 1.6 l/ha, two cover crops, *Centrosema pubescens* (Centro) at 2.5 kg/ha and *Pueraria phaseoloides* (Puero) at 2.0 kg/ha, hand weeding at 2 and 5 weeks after sowing (WAS) and no weeding. The experimental design was a randomized complete block design with four replications. Pre-emergence herbicide produced taller plants at 8 and 12 WAS and higher number of leaves at 12 WAS. Despite two hand weedings (at 2 and 5 WAS), the weed biomass of hand weeding treatment was not different from no weeding. Higher weed densities produced by hand weeding and no weeding at 12 WAS indicated that the two herbicides and the two cover crop treatments gave better weed control than both weed checks. Weed control was 4, 7 and 8 times better in pre-emergence, post-emergence and Centro; respectively, than no weeding at 8 WAS. Although Centro provided long term weed control, the herbicides were able to provide early protection for the maize plants. The highest maize yield of 2.21 t/ha obtained from Primextra Gold (atrazine + metolachlor) at 4l/ha was significantly higher than yields from the other treatments. Yield reduction of 24.5, 27.7, 34.4, 40.8 and 94.2% was obtained in 1.6 l/ha Aminoforce, Centro, hand weeding, Puero and no weeding, respectively, when compared to maize yield from Primextra Gold.

Key words: Mexican sunflower, cover crops, herbicides, hand weeding, weed control.

INTRODUCTION

Maize is an important cereal crop in Nigeria with a total production of about 11.0 million tons in 2019 (FAO, 2019). It is an important staple food that is also used as animal feed and raw materials in many industries such as flour mills, breweries, beverage and pharmaceuticals. The increased use of maize has placed a higher demand on the crop which is difficult to meet at the present level of production. In spite of the importance of maize, the yield per hectare does not match the demand in Nigeria. This is due to several factors such as weed infestation,

*Corresponding author. E-mail: tayoamosun@gmail.com.

unavailability of labour and low soil fertility (Imoloame, 2017).

Weed interference is a major maize production constraint in Southwestern Nigeria (Akinola and Salami, 2016). Yield losses caused by the presence of weeds in maize crops range from 10 to 80% (Akobundu and Ekeleme, 2000; Lagoke et al., 1998; Vargas et al., 2006). Silva et al. (2015) reported a 10% crop yield reduction in the presence of 10 plants m^{-2} of purple nut-sedge, which represented 960 kg ha^{-1} yield potential. The limitation in maize production due to weeds is proportional to the weed species that exist in the area, its density, cultural stage in which there is competition and climate and soil conditions (Vargas et al., 2006).

Diverse weed control measures employed in maize production are crop rotation, hand-weeding, cover crops, chemical weed control and integrated weed management (Horst and Hardter, 1994; Gbaraneh and Briggs, 2018; Amosun et al., 2015; Akinola and Salami, 2016; Chikoye et al., 2004). Intercropping legumes and cereals along with the principles of conservation agriculture are considered a way to sustainable food production in Africa (CIMMYT, 2018). When legumes are intercropped with maize they act as green manure adding nutrients to the soil, improving the nitrogen levels and reducing weeding labor. According to Gonzalez-Villalba et al. (2018), soil-cover and weed suppression varied between cover crops.

Tithonia diversifolia (Hemsl.) A. Gray (Mexican sunflower) is a very aggressive weed growing to a height of about 5 m or more and varies from highly branched at low populations (< 5 plants m^{-2}) to practically unbranched at high population (> 30 plants m^{-2}) (Ayeni et al., 1997). It is widely spread, growing on abandoned or waste lands, along major roads and waterways, and on cultivated farmlands (Ayeni et al., 1997). The aggressiveness of *T. diversifolia* offers it the ability to outcompete most arable crops in cultivated lands (Adesina et al., 2007). It eliminates plants (weeds and crops) by growing rapidly forming canopy cover over them; cutting off light to them and capable of causing considerable yield losses in cultivated crops (Akinola and Salami, 2016). Depending on the area of infestation, the Mexican sunflower may behave either as an annual or perennial plant. Its interference has resulted in crop failure if the weed is left uncontrolled in cultivated crops. Olabode et al. (1999) reported yield losses of 35, 51, 81 and 79% with delayed weeding of 4, 6, 8 weeks after planting (WAP) respectively in an uncontrolled *T. diversifolia* infested maize field, while the first 2 weeks after planting was observed as the maximum period of weed tolerance by maize in an infested field.

Various authors have reported the use of chemical (Tesfay et al., 2014; Chikoye et al., 2002; Makinde and Ogunbodede, 2008), mechanical (Amosun et al., 2016; Kayode and Ademiluyi, 2004), leguminous cover crops (Amosun et al., 2015; IDRC, 1998; Johnson et al., 1993), and their efficiency for sustainable weed control in maize production. However, there is little work comparing these different methods of management of Mexican sunflower in maize. This study was carried out to compare pre- and post-emergence herbicides, cover crops and manual weeding effects on Mexican sunflower control and performance of maize.

MATERIALS AND METHODS

The trials were conducted on fields that were heavily infested by Mexican sunflower at the Teaching and Research Farm, the University of Ibadan (latitude 7°30'N and longitude 4°3'E) in 2014 and at the Institute of Agricultural Research and Training, Moor Plantation, Ibadan (latitude 7°22'N and longitude 3°5'E) in 2015. The two sites are located in the derived savanna agro-ecology of Southwest Nigeria. The experimental fields were ploughed and harrowed and the six treatments were arranged in a Randomized Complete Block Design (RCBD) replicated four times. The treatments consist of a pre-emergence herbicide, a post-emergence herbicide, two cover crops, hand weeding and no weeding. They are 4l/ha Primextra Gold (atrazine + metolachlor) applied pre-emergence, 1.6 l/ha Aminoforce (2,4-D) applied post-emergence, 2.5 kg/ha *Centrosema pubescens*, 2.0 kg/ha *Pueraria phaseoloides*, hand weeding at 2 and 5 weeks after sowing (WAS) and no weeding.

Maize seeds, DMR SRY, were sown at a spacing of 75 cm x 25 cm in 2 m x 3 m plots at 3 seeds per hole. It was later thinned to one plant per stand to give a population of 53,333 plants/ha for all the treatments. Centro and Puero seeds were sown by drilling method in the intra-row same day maize was sown. The pre-emergence application of Primextra Gold was carried out within 24 h while post-application of Aminoforce was done 10 days after sowing (DAS) maize. Hand weeding was carried out on Centro and Puero plots at 2 WAS, while other treatments did not receive supplementary hand weeding till the end of the experiment. NPK fertilizer was applied at 90 kg/ha (Aduramigba-Modupe and Idowu, 2012) on maize plants at 3 WAS.

Data analysis

Pre–cropping routine analyses of the soil at the experimental fields were carried out. Data were collected on four plants randomly sampled and tagged on each plot. All data including plant height, number of leaves, leaf area, vine length of cover crops, weed density and weed biomass were taken at 4, 8, and 12 WAS and yield was also assessed at harvest. Weed density and biomass were obtained with the use of 25 cm x 25 cm quadrat (Elkson, 1942). Weeds were counted to obtain the density and oven dried at 80°C to obtain the dry weight. All data were subjected to analysis of variance (ANOVA) using the MSTATC computer package. The results of both years were not significantly different from each other; therefore, the two years were pooled together and analyzed.

RESULTS

Mexican sunflower was the predominant weed on the experimental plots. It had an average population density of 1,696 plants m^{-2}. It is a very fast growing plant that attained a height of 270-300 cm at 12 weeks. It was so evident on the no weeding plots that maize plants were shaded out. Other weed species also identified on the

Table 1. Physico-chemical properties of soil on experimental site.

Soil properties	2014	2015
pH (H_20)	7.10	6.3
Calcium (Cmol/kg)	0.98	2.77
Magnesium (Cmol/kg)	0.64	1.90
Sodium (Cmol/kg)	0.07	0.92
Potassium (Cmol/kg)	0.16	0.69
C.E.C. (Cmol/kg)	3.28	6.15
Organic carbon %	1.53	0.68
Nitrogen %	0.37	0.07
Available phosphorus (ppm)	35.71	30.15
Sand %	85.20	82.60
Silt %	5.40	9.20
Clay %	9.40	8.20

plots were *Ageratum conyzoides* L., *Amaranthus spinosus* L., *Aspilia africana* (Pers) C.D. Adams, *Bidens pilosa* L., *Boerhavia diffusa* L., *Chromolaena odorata* (L.) R.M.King and H. Robinson , *Commelina bengalensis* L., *Cynodon dactylon* (L.) Pers., *Euphorbia heterophylla* L., *Eleusine indica* (L.) Gaertn., *Laportea aestuans* (L.) Chew, *Phyllantus amarus* L., *Portulaca oleracea* L., *Spigelia anthelmia* L., *Synedrella nodiflora* (L.) Gaertn., *Talinum tringulare* (Jacq.) Willd. and *Tridax procumbens* L. The physico-chemical properties of soils at the experimental sites are shown in Table 1.

Maize growth

Significant differences ($p<0.05$) were observed in maize plant heights between treatments at 4, 8, and 12 WAS (Table 2). 4l/ha Primextra Gold produced taller plants while no weeding treatment produced shorter plants at 8 and 12 WAS. Differences ($p<0.05$) in the applied treatments were only obvious between 4 and 8 WAS, thereafter, there was no difference in the plant heights up to 12 WAS except for No weeding.

4l/ha Primextra Gold, 1.6l/ha Aminoforce, Puero and Hand weeding treatments produced maize plants with more leaves than Centro but maize plants in all treatments produced more leaves than No weeding at 4 WAS (Table 3). The maize plants in the pre-emergence herbicide plots were significantly higher ($p<0.05$) in leaf production than the post-emergence, Centro and No weeding at 8 and 12 WAS. As the plants grew older, pre-emergence treatment gave the highest number of leaves at 12 WAS than other treatments.

Data from Table 4 show that the leaf area of maize for all treatments increased from 4 to 8 WAS and decreased thereafter to 12 WAS. The leaf area of 411.8 cm^2 obtained from 4 l/ha Primextra Gold was more than other treatments at 4 WAS but comparable to 1.6 l/ha Aminoforce treatment. Leaf area values of maize plants from the two cover crops were similar while no weeding plants produced the smallest leaf area at 4 WAS. The two herbicides and two cover-crops produced maize with larger leaf area compared to Hand weeding and No weeding by 8 WAS. Maize plants in No weeding plots produced leaves with smaller leaf area at 12 WAS compared to other treatments.

Cover crop growth

Centro produced vine length and number of leaves which were significantly higher ($p<0.05$) than what was obtainable in Puero throughout the trial (Table 5). The average vine length of Centro reached up to 157.7 cm and Puero was just 90.5 cm while the average leaf number of Centro and Puero was 45.1 and 25.9, respectively. However, leaves produced by Puero (44.6 cm^2) were two times broader with a larger leaf area than Centro (22.4 cm^2). Centro exhibited its vigorous growth and climbing characteristics which became obvious from 6 WAS. Puero was not as vigorous as Centro; hence its climbing tendency was minimal for the duration of the trial.

Weed density and biomass

No weeding gave significantly higher ($p<0.05$) weed density than the other treatments at 4WAS (Table 6). At this period also the two herbicides and Hand weeding provided adequate early protection for the maize plant from the weed infestation. Lower weed densities observed at 4 WAS in the herbicides and Hand weeding was as a result of the treatments applied immediately after sowing (pre-emergence), 10 DAS (post-emergence) and 2 WAS (Hand weeding). The cover crops just started spreading at this time and the ground had not been fully covered. Weed density at 8 WAS showed more Mexican

Table 2. Effect of weed control treatments on maize plant height.

Treatment	Rate	4WAS (cm)	8WAS (cm)	12WAS (cm)
Maize + Primextra Gold*	4.0 L/ha	30.9[a]	253.6[a]	284.7[a]
Maize + Aminoforce**	1.6 L/ha	25.4[ab]	239.5[ab]	255.4[a]
Maize + Centrosema	2.5 kg/ha	26.5[ab]	220.3[b]	252.4[a]
Maize + Pueraria	2.0 kg/ha	28.8[a]	229.4[ab]	279.3[a]
Maize + Hand weeding	2 & 5 WAS	26.1[ab]	227.7[b]	247.1[a]
Maize + No weeding	-	23.1[b]	177.1[c]	180.2[b]

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT. *Primextra Gold is a proprietary formulation of Syngenta containing 370 g/l atrazine + 290 g/l metolachlor. **Aminoforce is a proprietary formulation of Jubaili Agrotec containing 720 g/l 2, 4-Dimethyl ammonium salt.

Table 3. Effect of weed control treatments on maize number of leaves.

Treatments	Rate	4WAS (no.)	8WAS (no.)	12WAS (no.)
Maize + Primextra Gold*	4.0 L/ha	8.5[a]	13.6[a]	14.5[a]
Maize + Aminoforce**	1.6 L/ha	8.3[a]	12.6[bc]	13.3[b]
Maize + Centrosema	2.5 kg/ha	7.6[b]	12.6[bc]	13.3[b]
Maize + Pueraria	2.0 kg/ha	8.3[a]	13.3[ab]	13.7[ab]
Maize + Hand weeding	2 & 5 WAS	8.3[a]	13.0[abc]	13.4[b]
Maize + No weeding	-	5.7[c]	12.1c	12.8[b]

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT. *Primextra Gold is a proprietary formulation of Syngenta containing 370 g/l atrazine + 290 g/l metolachlor. **Aminoforce is a proprietary formulation of Jubaili Agrotec containing 720 g/l 2, 4-Dimethyl ammonium salt.

Table 4. Effect of weed control treatments on maize leaf area.

Treatments	Rate	4 WAS (cm^2)	8 WAS (cm^2)	12 WAS (cm^2)
Maize + Primextra Gold*	4.0 L/ha	411.8[a]	636.3[a]	572.3[a]
Maize + Aminoforce**	1.6 L/ha	347.9[ab]	530.1[ab]	507.7[a]
Maize + Centrosema	2.5 kg/ha	302.9[bc]	459.1[b]	518.1[a]
Maize + Pueraria	2.0 kg/ha	273.7[c]	503.7[ab]	487.1[a]
Maize + Hand weeding	2 & 5 WAS	283.0[bc]	283.0[c]	396.4[a]
Maize + No weeding	-	182.8[d]	281.8[c]	126.4[b]

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT. *Primextra Gold is a proprietary formulation of Syngenta containing 370 g/l atrazine + 290 g/l metolachlor. **Aminoforce is a proprietary formulation of Jubaili Agrotec containing 720 g/l 2, 4-Dimethyl ammonium salt.

sunflower in Hand weeding and Puero even though these are only significantly higher ($p<0.05$) than pre-emergence 4l/ha Primextra Gold. At 12 WAS, lower weed densities were obtained in the two herbicides and the two cover crops.

There were no differences in weed biomass among the treatments at 4 WAS (Table 7). The effect of applied treatments was obvious at 8 WAS, where significantly lower ($p<0.05$) weed biomass was obtained in the Centro, pre- and post-emergence herbicide treatments, while Puero and Hand weeding were comparable to No weeding. Despite two Hand weedings (at 2 and 5 WAS), the weed biomass of Hand weeding treatment was not different from No weeding. At 8 WAS, weed control was still effective in the two herbicide treatments and Centro has started spreading aggressively. Weed control was 4, 7, and 8 times better in pre-emergence, post-emergence and Centro respectively, compared to No weeding. Although Centro provided long term weed control, the herbicides were able to provide early protection for the maize plants. Cover-crops had fully developed their canopies by 12 WAS, and shaded out the weeds, hence

Table 5. Effect of weed control treatments on growth parameters of cover crops.

Cover crop treatments	Rate (kg/ha)	4 WAS	8 WAS	12 WAS
Vine length (cm)				
Maize + Centrosema	2.5	27.1[a]	60.8[a]	157.7[a]
Maize + Pueraria	2.0	8.2[b]	59.8[b]	90.5[b]
Leaf number				
Maize + Centrosema	2.5	20.4[a]	13.6[a]	45.1[a]
Maize + Pueraria	2.0	13.5[b]	8.8[b]	25.9[b]
Leaf area (cm^2)				
Maize + Centrosema	2.5	9.8[b]	18.2[b]	22.4[b]
Maize + Pueraria	2.0	16.3[a]	38.9[a]	44.6[a]

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT.

Table 6. Effect of weed control treatments on weed density.

Treatment	Rate	4 WAS (No./m^2)	8 WAS (no/m^2)	12 WAS (no/m^2)
Maize + Primextra Gold*	4.0 l/ha	33[c]	44[b]	24[b]
Maize + Aminoforce**	1.6 l/ha	52[c]	89[ab]	39[b]
Maize + Centrosema	2.5 kg/ha	178[b]	98[ab]	30[b]
Maize + Pueraria	2.0 kg/ha	181[b]	156[a]	13[b]
Maize + Hand weeding	2 & 5 WAS	64[c]	143[a]	86[a]
Maize + No weeding	-	393[a]	93[ab]	118[a]

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT. *Primextra Gold is a proprietary formulation of Syngenta containing 370 g/l atrazine + 290 g/l metolachlor. **Aminoforce is a proprietary formulation of Jubaili Agrotec containing 720 g/l,2, 4-Dimethyl ammonium salt.

the reduced weed weight of Mexican sunflower. Both herbicides and cover crops had significantly lower ($p<0.05$) weed biomass than Hand weeding and No weeding. As expected, No weeding had the highest weed biomass.

Maize yield

Figure 1 shows that the highest maize yield of 2210.5 kg/ha was obtained from Primextra Gold and it was significantly higher ($p<0.05$) than yields from the cover-crops and the control treatments. This result is expected as only the pre-emergence herbicide treatment provided an early protection for the maize crop against weed interference. Yields from 1.6 l/ha Aminoforce, Centro, Puero and Hand weeding were not different while No weeding was significantly lower ($p<0.05$) than all other treatments. The two Hand weedings (2 and 5 WAS) were as effective as the cover crops. Whereas Centro and Puero treatments provided cover against weeds later in the season (8 to12 WAS), the maize plots were exposed to weed pressure at the early stage of growth. In comparison with the yield of 4.0 l/ha Primextra Gold, yield reductions of 24.5, 27.7, 34.4, 40.8, 94.2% were recorded in Aminoforce, Centro, hand-weeding, Puero and No weeding, respectively.

DISCUSSION

The various treatments effects could be seen at 4, 8 and 12 WAS. The applied treatments were observed to affect the growth and yield of maize at various degrees, even though differences in the treatments were obvious between 4 and 8 WAS. Thereafter, at 12 WAS, most of the treatment parameters were not showing obvious differences. The pre-emergence and post-emergence herbicides and cover crops influence the height of maize plants up to 12 WAS. Hence, plants in all the applied treatments grew taller than No weeding. Production of lesser leaves by maize plants of Centro treatments at 4 WAS resulted from the interspecific competition between the cover-crop and maize plants. Better growth performance of maize in 4 l/ha Primextra Gold applied pre-emergence could be attributed to reduced crop-weed competition at the initial stage of growth.

The pre- and post-emergence herbicides were able to

Table 7. Effect of weed control treatments on weed biomass.

Treatment	Rate	4WAS (g/m^2)	8WAS (g/m^2)	12WAS (g/m^2)
Maize + Primextra Gold	4.0 L/ha	13.68	18.72^b	10.64^c
Maize + Aminoforce	1.6 L/ha	24.64	10.40^b	19.08^c
Maize + Centrosema	2.5 kg/ha	16.20	9.20^b	22.00^c
Maize + Pueraria	2.0 kg/ha	14.28	43.68^a	8.24^c
Maize + Hand weeding	2 & 5 WAS	28.64	63.52^a	41.52^b
Maize + No weeding	-	35.16	74.24^a	163.56^a

Mean values with the same letter in each column are not significantly different at 5% level of probability by DMRT. *Primextra Gold is a proprietary formulation of Syngenta containing 370 g/l atrazine + 290 g/l metolachlor. **Aminoforce is a proprietary formulation of Jubaili Agrotec containing 720 g/l; 2, 4-Dimethyl ammonium salt.

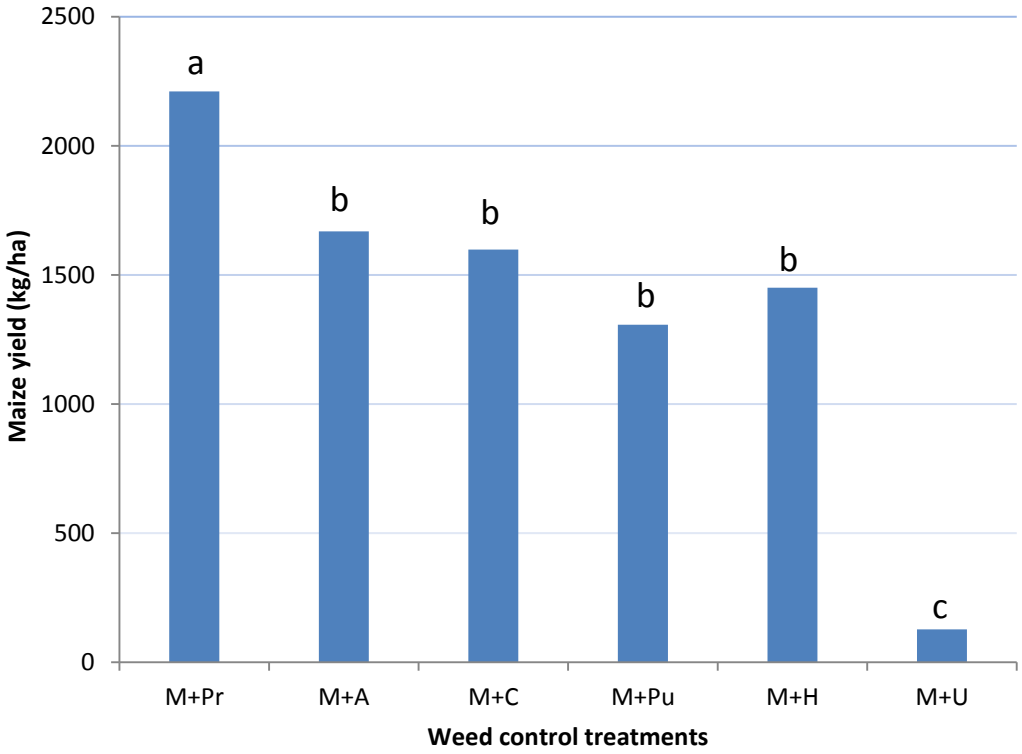

Figure 1. Effect of weed control treatments on maize yield. M+Pr = Maize + Primextra Gold, M+A = Maize + Aminoforce, M+ C = Maize + Centrosema, M+Pu = Maize + Pueraria, M+H = Maize + Hand weeding, M+U = Maize + No Weeding.

control the Mexican sunflower at the critical period of weed control in maize which is between the first 4 to 6 weeks after emergence (Cumberland et al., 1971; Takim, 2012). It was reported that if weeds are not controlled at this period, there is a critical crop-weed competition with grain losses reaching between 35 and 70% (Ford and Pleasant, 1994). The cover-crops, on the other hand, require time for germination and establishment, thereby, not providing adequate cover for the maize crop at this essential period of growth. Although Centro and Puero provided long term weed control, the herbicides were able to provide early protection for the maize plants. Centro grew faster than Puero but the latter (at 12 WAS) provided a better ground cover due to broader leaves and greater leaf area. The cover-crops had fully developed their canopies by 12 WAS, and shaded out the weeds, hence, the reduced weed weight of Mexican sunflower. Both herbicides and cover-crops influenced the reduction of weed biomass than hand weeding and no weeding.

Hand weeding operation carried out at 5 weeks in the Hand weeding treatment would have exposed and stimulated the germination and growth of more weed

seedlings, resulting in the high density of 143 plants m^{-2} and high weed biomass of 63.25 g m^{-2} recorded at 8 WAS in this treatment. Mexican sunflower had the initial growth advantage before the germination and establishment of the cover-crops. Results indicated that the herbicides and the cover crops gave better weed control than Hand weeding and No weeding treatments at 12 WAS. Apart from the imposed treatments, intraspecific competition within the Mexican sunflower population was also responsible for the weed reduction from 4 to 12 WAS.

Before the post-emergence herbicide was applied at 10 DAS, the maize plants were already exposed to weed-crop competition for that period, which eventually became obvious on the grain yield. This agrees with Maqsood et al. (1999) that maize infested with weeds for the first 6-8 weeks of growth will have a drastic decrease in the grain yield. The yield reduction of 94.2% recorded in No weeding treatment agrees with the report that uncontrolled Mexican sunflower infestation can lead to total crop failure (Olabode et al., 1999).

Conclusion

Mexican sunflower responded very well to pre-emergence application of Primextra Gold. It is very obvious that an early management of the weed is important, because the post-emergence treatment applied at 10 DAS reduced grain yield by 24.5%. Either herbicides or cover-crops alone cannot effectively be used in the management of Mexican sunflower. Therefore, an integrated weed management approach will be a better option that ensures the weed is adequately managed at the critical period of weed control. More research is necessary to investigate the integration of these methods.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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