Advances in Weed Science formerly Planta Daninha

Efficiency of Atrazine+2,4D or Paraforce in pre-emergent weed control of selected early maturing maize varieties (*Zea mays*)

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Abstract: Background: Atrazine, a pre-emergent weed control, can be mixed with paraforce or 2,4-D, however, the efficiency of the mixture nor the growth and yield performance of maize varieties under this treatment in the tropics is well establihsed. **Objective:** To determine efficacy of atrazine mixed with paraforce or 2,4-D as weed control method and yield performance of four yellow maize varieties (PVASYN8F$_2$, BR9928-5R-Y, DSTRSYN2-Y and PVASYN2F$_2$). **Methods:** In two years, four yellow maize varieties (PVASYN8F$_2$, BR9928-5R-Y, DSTRSYN2-Y and PVASYN2F$_2$.) and atrazine (1.5kg ha^{-1}) mixed with paraforce, atrazine mixed with 2,4-D (1.5 L ha^{-1} in equal ratio; hand weeding and weedy (check) plots were arranged in split-plot using randomized complete block design with three replications. Fertilizers and pest control were done as practiced in the Teaching and Research Farm. Data were collected on maize vegetative and reproductive characters and analyzed using SAS ver 9.4 and Microsoft Excel. **Results:** Weed control efficiency (80%) and number of leaves per plant recorded for atrazine + paraforce plot were the highest. No significant grain yield difference was recorded among the varieties, but maximum grain loss was observed in no weeding field and the lowest was found in field treated atrazine + paraforce followed by Atrazine + 2,4-D. BR-9928-5R-Y among the varieties showed the least 44% grain loss while PVA SYN 2 F$_2$ had the highest 53%. **Conclusions:** Atrazine + paraforce outperformed atrazine + 2,4-D as a pre-emergent weedicide and BR-9928-5R-Y variety produced the highest grain yield and minimum grain loss across all the treatments.

Keywords: Weedicides; Grain Yield; Hand Weeding; Grain Loss; Maize

Journal Information:
ISSN - 2675-9462
Website: http://awsjournal.org
Journal of the Brazilian Weed Science Society

How to cite: Murtadha MA, Olajoke SB. Efficiency of Atrazine+2,4D or Paraforce in pre-emergent weed control of selected early maturing maize varieties (Zea mays). Adv Weed Sci. 2024;42:e020240017
https://doi.org/10.51694/AdvWeedSci/2024;42:00017

Approved by:
Editor in Chief: Anderson Luis Nunes
Associate Editor: José Barbosa dos Santos

Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Received: March 18, 2024
Approved: August 13, 2024

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1. Introduction

Maize, the most important food and feed crop in the grass family, is widely and densely grown in Nigeria for its high yield potential, particularly during the wet season. However, it is sparsely sown in the dry period, with relatively wide spacing, subjecting it to competition with various weeds, which often inflicts huge losses ranging from 28 to 100 percent of grain (Mehmeti et al., 2019; Chauhan, 2020). This loss is often graded as weeds > insects > plant diseases > and virus with values of 37% > 18% > 16% > 2% (Barros et al., 2017). The interference of weeds with maize plants becomes more severe, particularly in the early stage of maize growth (Mishra, 1997), whereas by the time the crop establishes, the severity of loss due to weeds becomes less. This indicates the significant role of pre-emergence weed control on the overall performance at subsequent stages of maize growth (Amosun et al., 2021; Chojnacka et al., 2023).

Generally, weeds compete with crops indirectly by producing allelopathic matter (Zohaib et al., 2016) and directly for light, water, nutrients, space and habitat for destructive insects and pathogens. This competition with the crop usually results in reduced morphological, phenological and other developmental attributes of the crop. Severe effects of weeds on plant height and number of cobs per plot and number of grains per cob were reported (Oerke, Dehne, 2004; Naderi et al., 2024). Compared with a weed-free field, maize on weed infested land develops short plants, long days to 50% silking (Anorvey et al., 2018), long ASI and a reduced yield of 0.13 tha-1 (Reid et al., 2014). However, in their report, Dangari et al. (2024) observed short days to flowering in sweet corn.

Weeds can be controlled by cultural, biological and chemical measures. Hand weeding, a common cultural control in subsistence farming, is achieved by pulling weeds by hand, cutting with a hoe and using other crude tools like cutlass. The method, though, remains the most effective and safest, it is the most tedious, highly demanding for manpower and farm labour hours (Chikoye et al., 2004). The scarcity of labour nowadays has rendered the manual/hoe weeding economically unviable for maize grain sustainability (Oerke, Dehen, 2004), especially if "zero hunger", an important aspect of the Sustainable Development Goals (SDGs) of the United Nations, is to be achieved. Other cultural methods include, but are not limited to, crop rotation, inter-row cultivation, sowing cover crop and intercropping with compatible crops to suppress weeds (Melander et al., 2005; Hughes, 2006; O'Gara, 2007).

A few herbicide options available for weed control in maize are atrazine and paraforce, which are commonly used solely before at sowing. Compared with a weedy plot, a higher grain yield was realized from a plot treated with herbicide by 77% to 96.7% grain yield (Khan et al., 1998). Atrazine, a 4-hydroxyphenylpyruvate dioxygenase (HPPD), is widely used in maize production (Chhokar et al., 2019) and has proven its effectiveness, particularly in delaying the start of the weed stress on maize (Padilha et al., 2016; National Center for Biotechnology Information, 2021). Paraforce (Paraquat dichloride (200 g paraquat)/L SL.) is also widely applied in maize farms; though, there is a growing concern about its lethality, particularly if ingested. Mojeed (2023) reported for Premium Times a wide call to ban this herbicide. 2,4-Dichlorophenoxyacetic acid (2,4-D) is the active ingredient of 2,4-D and has for many years been used to control several weeds in cereal crops.

Herbicidal control of weeds is not only economical, effective and productive in modern agriculture. It also gives rapid and unmatched results in a very short time after application. Imoloame (2017) reported that weed infestation was reduced and high grain yield and economic returns were obtained in herbicide mixtures. Herbicide mixtures were thus recommended for farmers in the Southern Guinea ecology of Nigeria. Iqbal et al. (2020) concluded that atrazine at 1.2 kg active ingredient (i.a.) per ha and pendimmethline at 1.0 a.i. kg ha-1 were important in reducing weed emergence in the early growth stages of maize.

However, problems associated with its injudicious application included, environmental pollution, and the development of weed resistance against weedicides among others. Good practices in herbicidal application involve the use of the least, but effective quantity of herbicide in the control of weeds. Nevertheless, with the intensive use of weedicides, a minimum of 10 percent loss of agricultural produce is often recorded annually in most agricultural systems (Zimdahl, 2004). This negative phenomenon calls for the inclusion of various strategies for controlling weeds in maize production (Anorvey et al., 2018). The mixing of chemicals is widely practiced as a means to totally control weeds in one application. The nature of the active ingredient in each weedicide should therefore be considered. Atrazine can be mixed with paraforce or 2,4-D to control both broad- and narrow-leaf weeds. For instance, Hussain et al. (2020) reported that a mixture of acetoclor and atrazine had a greater positive impact as a pre-emergence herbicide in controlling weeds in sugarcane crops. The missing information is the efficacy of the mixture in controlling weeds and its control ability above weedy fields or hand weeding practices. This study aimed to reveal the efficacy of atrazine mixtures over manual weeding and check (non-weeded) maize weed control. It also aimed at identifying the maize variety that respond to the most efficient management method.

2. Material and Methods

2.1 Site description

A field experiment was conducted at the Obafemi Awolowo University (OAU), Teaching and Research Farm in the 2019 and 2020 growing seasons. Average weather parameters (rainfall, maximum and minimum temperatures) for the period of the two years is given in Table 1.

Table 1 - Weather parameters (rainfall, maximum and minimum temperatures) for the 2019 and 2020 maize growing seasons

Month	Rainfall (mm)	Temperature (C)
April	228.1	19.1
May	198.1	20.1
June	190.2	20.2
July	197.1	19.8

Source: NIMET (the Nigerian Meteorological Agency), Abuja, Nigeria

Site soil samples collected at 0–20 cm contained: pH (H20) = 6.40, total nitrogen (%) = 0.12, organic carbon (%) = 0.94; available P (ppm) Bray I = 5.52, Cation exchange capacity (cmol/kg) = 15.24, Exchangeable cations (cmol/kg): K = 1.41, Mg = 2.51, Ca = 0.21, Sand (%) = 80.02, Silt (%) = 9.86 and Clay (%) = 10.12 and the soil was classified as sandy loam.

2.2 Land preparation and experimental design

A total area of 43.25 m × 17.5 m (756.85 m^2) was ploughed twice and divided into three blocks of 12.5 m x 9 m each, separated horizontally and vertically by 1m to serve as a border among the plots. Each block was further divided into four distinct plots and randomly assigned as the main plot to weed treatments: control (no weeding), 50% Atrazine + 50% Paraforce; 50% Atrazine + 50% 2,4-D (applied at the second day after sowing) at 1.5 kg ha-1 Atrazine and one (1) litre ha-1 of 2,4-D or Paraforce as recommended by the manufacturer; and hand weeding (weed removal four times in the season). The physicochemical properties of these herbicides are given in Table 2. A plot was 6 m2, and was further divided into eight rows randomly allocated at two rows per maize variety: PVA SYN 8F2; PVA SYN 2F2 (sourced from the International Institute of Tropical Agriculture, Ibadan, Nigeria); BR 9928-5R-Y and DTSTR SYN 2-Y (procured from the Institute of Agriculture Research and Training, Ibadan, Nigeria). The arrangement of treatment and maize varieties using RCBD in a split plot arrangement is presented in Figure 1.

The maize seeds were sown at a rate of 25 kg ha^{-1} at a depth of 2–3 cm using a sowing distance of 0.5 m x 0.75 m between and within rows, respectively. Two weeks after sowing, seedlings were thinned to one plant stand; fertilized with N.P.K.20:10:10 at a rate of 80 kg N, 60 kg P and 60 kg k ha-1 in three doses. Armyworm and other species were controlled by caterpillar force (Emamectin Benzoate, 5% WDG) at a rate of 3.5 litre ha-1. Harvesting begins 56 days

Treatment x Varieties	Block 1				Block 2				Block 3			
Treatments (main plot)	No Weeding				Hand Weeding				Atrazine + 2,4-D			
Varieties (sub-plot)	V1	V2	V3	V4	V4	V1	V3	V2	V2	V4	V1	V3
Treatments (main plot)	Atrazine+ Paraforce				No Weeding				Atrazine+ Paraforce			
Varieties (sub-plot)	V2	V4	V1	V3	V1	V3	V4	V2	V1	V2	V3	V4
Treatments (main plot)	Atrazine + 2,4-D				Atrazine+ Paraforce				Hand Weeding			
Varieties (sub-plot)	V3	V1	V4	V2	V4	V1	V2	V3	V2	V1	V4	V3
Treatments (main plot)	Hand Weeding				Atrazine + 2,4-D				No Weeding			
Varieties (sub-plot)	V2	V3	V1	V4	V3	V1	V4	V2	V1	V3	V2	V4

Keys: V = variety

Figure 1 - Description of the field layout of the experimental site

after sowing. The experiment was a randomized complete block design in a split plot arrangement.

Table 2 - Physicochemical properties of herbicides applied in this study

Properties	Atrazine1	2, 4-D2	Paraforce3
Chemical formula	$C_8H_{14}ClN_5$	$C_8H_6C_{12}O_3$	$C_{12}H_{14}C_{12}N_2$
Molar mass	215.69 g·mol^{-1}	221.04 g·mol^{-1}	257.16 g·mol^{-1}
Density	1.187 g cm^{-3}	1.563 g cm^{-3}	1.25 g cm^{-3}
Melting point	175 °C	140.5 °C	175 to 180 °C
Boiling point	200 °C	160 °C	> 300 °C
Solubility in water	7 mg/100 mL	900 mg L^{-3}	High
Type	Selective pre- or poste-mergence herbicide	Post-emer-gence	Post-emer-gence

1 - Atrazine. (2023, February 4). In *Wikipedia*. https://en.wikipedia.org/wiki/Atrazine
2 - 2,4-Dichlorophenoxyacetic acid. (2022, December 13). In *Wikipedia*. https://en.wikipedia.org/wiki/2,4-Dichlorophenoxyacetic_acid
3 - Paraquat. (2022, December 10). In *Wikipedia*. https://en.wikipedia.org/wiki/Paraquat

2.3 Data collection

Four plants were randomly chosen from the two rows representing each variety in a block and tagged for data recording. The data recorded were: days to 50% germination, days to 50% anthesis, days to 50% silking, number of leaves per plant and number of cobs per plant. Number of leaves per plant was counted weekly from the fourth week until the ninth week, when the plant produced obvious tassel. The cobs on the tagged plants were harvested, shelled and weighed separately for yield parameters, which included number of cob grains row^{-1}, and number of rows cob^{-1}. Both grain yield and 100-seed weight were measured with a sensitive balance, while grain moisture was determined by hygrometer and the results of grain yield and 100-seed weight were adjusted to 14% moisture content.

To estimate weed control efficiency, samples of weed were obtained using a 0.25 m × 0.25 m quandrant thrown randomly at three places in each block and the weeds within were harvested the day before weeding. The harvested weeds were dried in an oven at 65°C for 24 hours and converted into grams. Weed Control Efficiency (WCE) was calculated from weed control treatments as follows:

$$\textit{Weed control efficiency} = \frac{WDc - WDt}{WDc} \text{ x } 100 \quad \text{(Šarić, 1991)}$$

WD_C: Weed Dry Matter in Weedy Check;
WD_T: Weed Dry Matter in a Treatment.

Relative yield loss due to weeds was calculated based on the maximum yield obtained from a treatment or treatment combination as follows:

$$\textit{Relative yield loss} = \frac{My - Yt}{My} \text{ x } 100$$

M_Y= maximum yield from a treatment,
Y_T = yield from a particular treatment.

$$\textit{Herbicide Efficacy} = \frac{WfWc\text{-}WfWt}{WfWc} \text{ x } 100 \quad \text{Yadav et al. (2015)}$$

W_fW_C= Dry weight of weeds in control plot and
W_fW_T = Dry weight of weeds in a particular treatment.
A simple linear regression analysis was run to determine the relationship between number of leaves per plant and days from sowing in response to each weed control method. The formula used was:

$$y = a + b \times$$

Where:
Y = number of leaves per plant measured weekly starting from week 4
X = weed control method (atrazine+ 2,4-D, atrazine + paraforce, manual weeding and no weeding)

2.4 Data analysis

Data were subjected to a two-way analysis of variance using the PROC NLMIXED function variance of statistical analysis software (SAS version 14). Significant means were separated using the 5% level of significance of the Duncan Multiple Range Test. Orthogonal analysis was employed to determine significant differences between groups of treatments. Microsoft Excel was used to draw a graph showing the relationship between the number of leaves per plant and days from sowing as affected by weed control methods.

3. Results and Discussion

Overall cross check on the harvested weeds revealed that the most common were: corn grass (*Rottboellia cochinchinensis*), billy goat weed (*Ageratum conyzoides* L.,), Benghal daflower (*Commelina benghalensis* L.,), morning glory (*Ipomoea involucrata* P. Beauv.), and copper leaf (*Acalypha ciliata* Forssk). The varieties showed significant variation for days to 50% germination and number of rows per cob (Table 3) and insignificant variance for other characters. Seeds of PVA SYN $2F_2$ emerged at 5.55 days to become the fastest among other varieties. Number of grain row cob^{-1} was the highest in DTSTR SYN 2-Y (14.86), while the least was found in PVA SYN $2F_2$ with 12.42 rows. Variation in the performance of maize varieties due to successful weed control and efficiency is well recognized. The variation in days to 50% germination suggested that the maize seed sown in soil treated with a mixture of pre-emergent herbicides two days after sown has variability in tolerating the residual effects of herbicides applied, as shown by PVA SYH 2F2. A uniform and vigorous seedling is expected from early emergence as it will ensure a good plant population and yield (Shirin et al., 2008; Abbasian et al., 2013). High germination usually indicates viability, a property of seeds that supports seed growth under optimal conditions (Baldwin et al., 2006). A similar observation was also noticed by Sakadzo et al. (2018), who grouped inbred lines into three in terms of their tolerance to weedicide effects.

The variance analysis regarding parameters like number of seed row^{-1}, 100-seed weight (g) and grain yield per plant showed a non-significant difference ($P < 0.05$). However, a numerical difference was reflected among the tested varieties. The highest number of seed row^{-1}, 100-seed weight (g) and grain yield plant^{-1} was displayed by BR 9928-5R-Y with 24.96±1.42, 13.27±0.74 and 75.97±3.85, respectively, and the lowest was obtained from weedy check plots. This variation reflected the variability in the varieties' inherent ability to tolerate severe competition for resources between the crop plant and weeds. In the weed control treatments, however, there were sufficient resources for the growing maize plants. Zystro et al. (2012); Shelton et al. (2013); Job et al. (2023) revealed the existence of genetic and phenotypic variation among maize varieties for weed competitiveness.

Crops in hand weeding had the longest days to 50% anthesis and silking with 59.33 and 61.33 days respectively. The shortest days were obtained in no weeding with 57.77±0.28 and 59.70±0.28 days, respectively (Table 4.). This observation, which was contrary to the report of Anorvey et al. (2018), was in line with the report of Dangari et al. (2024), which showed that weed competition accelerated flowering processes in sweet corn, and suggested that maize plants enjoyed more nutrients in the soil. This might have allowed optimum growth before transitioning to the reproductive stage, while plants without weeding were under relative stress effect of weeds and displayed a rapid transition to flowering.

Hand weeding also supported the highest number of seed row^{-1} (27.50±0.1.09) but moderate seed weight (11.96±0.64 g). The heaviest grain,14.13±0.86 g, was found in field treated with atrazine + paraforce. The relatively late appearance of floral parts in maize under hand weeding reflected that the plants were not under weed stress and were robustly utilizing available nutrients compared to weedy plots. When weeds in field-grown maize are controlled, the source will have a better chance to translocate available sink to the maximum grains formed and also maintain their weight.

The relative yield loss to the weed caused by the control methods is given in Figure 2. Maximum grain loss was observed in no weeding field and the lowest was found in field treated atrazine + paraforce. This is expected as a field

Table 3 - Varietal variation for growth habit of maize (*Zea mays* L.) in four weed control methods

Characters	Varieties			
	PVA SYN $8F_2$	BR 9928-5R-Y	DTSTR SYN 2-Y	PVA SYN $2F_2$
Days to 50% germination	6.00± 0.30^{ab}	6.60±0.27^{a}	6.00±0.33^{ab}	5.55±0.28^{b}
Days to 50% anthesis	58.22± 0.30^{a}	58.44±0.29^{a}	58.28±0.31^{a}	58.44±0.39^{a}
Days to 50% silking	60.13± 0.30^{a}	60.42±0.30^{a}	60.28±0.31^{a}	60.42±0.39^{a}
Anthesis-silking interval	1.91± 0.07^{a}	1.98±0.02^{a}	2.00±0.00^{a}	1.98±0.02^{a}
Number of cob plant^{-1}	1.44± 0.08^{a}	1.58±0.10^{a}	1.40±0.09^{a}	1.61±0.10^{a}
Number of seed row^{-1}	23.37±1.18^{a}	24.96±1.42^{a}	22.47±1.32^{a}	23.42±1.48^{a}
Number of row cob^{-1}	14.35±1.07^{ab}	12.84±0.89^{ab}	14.86±1.17^{a}	12.42±0.83^{b}
100-seed weight (g)	12.17±0.56^{a}	13.27±0.74^{a}	12.48±0.76^{a}	11.69±0.59^{a}
Number of leaf plant^{-1}	9.44±0.27 ^{a}	9.31±0.29^{a}	9.30±0.31^{a}	9.19±0.30^{a}
Grain yield plant^{-1}	75.65±4.12^{a}	75.97±3.85^{a}	65.88±3.63^{a}	66.93±3.45^{a}

Note: Means followed by the same letter within each row are not significantly different ($P \leq 0.05$), as indicated by Duncan's Multiple Range Test

Table 4 - Effects of weed control methods on the growth performance of four maize varieties

Characters	Treatment			
	ATRA+2,4-D	ATRA+Para	Hand weeding	N weeding
Days to 50% germination	6.23±0.28[a]	6.20±0.33[a]	5.73±0.30[a]	5.90±0.35[a]
Days to 50% anthesis	57.85±0.28[b]	58.48±0.31[ab]	59.33±0.38[a]	57.77±0.28[b]
Days to 50% silking	59.83±0.28[b]	60.44±0.31[b]	61.33±0.38[a]	59.70±0.28[b]
Anthesis-silking interval	1.98±0.02[a]	1.96±0.03[a]	2.00±0.00[a]	1.93±0.07[a]
Number of cob plant^{-1}	1.39±0.09[a]	1.61±0.10[a]	1.43±0.09[a]	1.58±0.09[a]
Number of seed row^{-1}	21.74±1.37[b]	22.89±1.25[b]	27.50±1.09[a]	22.40±1.50[b]
Number of row cob^{-1}	15.28±1.09[a]	11.59±0.73[b]	10.79±0.31[b]	16.79±1.29[a]
100-seed weight (g)	11.13±0.47[b]	14.13±0.86[a]	11.96±0.64[b]	12.39±0.57[ab]
Number of leaf plant^{-1}	9.00±0.27[a]	9.44±0.27[ab]	9.91±0.34[a]	8.91±0.34[b]
Grain yield plant^{-1}	66.91±3.83[a]	73.92±2.72[a]	76.18±5.54[a]	65.64±3.95[a]

Note: Means followed by the same letter within each row are not significantly different (P ≤ 0.05), as indicated by Duncan's Multiple Range Test

overgrown by weeds usually leads to reduced grain of crops as a result of competition for water, sunlight and weed allopathy.

Relative grain yield loss as a result of maize tolerance to weed is displayed in Figure 3. According to the result, under no weeding and atrazine with paraforce or 2,4-D, BR-9928-5R-Y responded positively to the management methods employed by showing <45% yield loss, while, PVA SYN 2 F_2 was the most sensitive by having >50% grain yield loss. These differences offer an opportunity to improve weed resistance among these varieties. The fact that under, BR-9928-5R-Y had the least grain loss in weedy check plot suggests its better yielding performance compared with other varieties and the possibility of its selection in future maize improvement for weedy environments.

Efficiency of atrazine mixed with paraforce and atrazine with 2,4-D was compared in Figure 4. The results showed that efficiency of atrazine + paraforce was 80% and above while that of atrazine + 2,4-D was less than 40%. This is in consonance with the reports of Hussain et al. (2020) and Iqbal et al. (2020) on sugarcane and sorghum respectively. The better performance of atrazine mixed with paraforce can be related to its functionality being broad spectrum herbicde, while, 2,4-D is selective (Oregon State University, 2024).

The relationship between number of leaves per plant and days after sowing as affected by weed control methods is given in Figure 5. There was a positive correlation between number of leaves per plant and days to sowing. The regression model revealed that with each unit increase in days after sowing, there was an increase ranging from 1.698 (atrazine + paraforce) to 1.466 (no weeding) in number of leaves. Also, the observed R^2 in atrazine + paraforce, atrazine + 2,4-D, manual weeding and no weeding were 0.862, 0.832, 0.829 and 0.782, respectively. The value of 0.862 R^2 indicated that the increase in leaf number in atrazine + paraforce treated plots was 86.20% caused by the weed suppression-effect of the herbicide, while

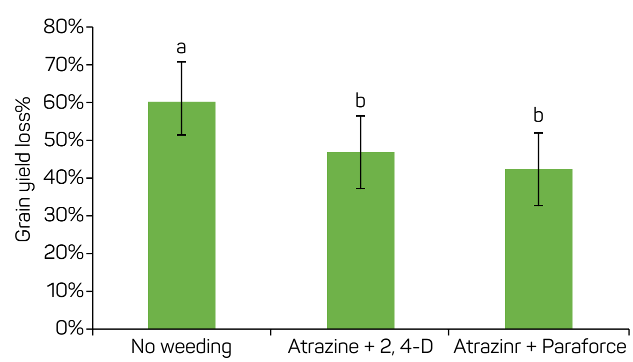


Figure 2 - Relative yield loss resulting from the use of atrazine mixture and no weeding management methods in maize

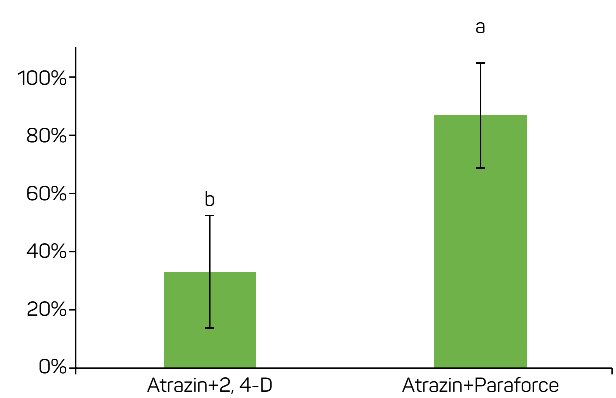
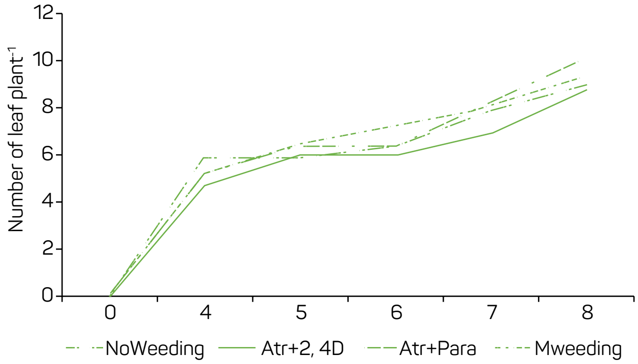


Figure 4 - Weed control efficiency of the herbicides employed in the maize

13.80% was due to other positively contributing factors not considered in this study. The low value of the intercept of atrazine + 2,4-D did not support its high R^2 value, thus it cannot be chosen as being as effective as atrazine + paraforce. Generally, application of pre-emergent weedicide or continual weeding tends to suppress weed attacks



Y = 1.698x + 0.108, R2 = 0.862 Atr+Para)
Y = 1.448x + 0.325 (R2 = 0.832 Atr+2,4D)
Y = 1.591x + 0.477, R2 = 0.829 HWeeding)
Y = 1.466x + 0.679, R2 = 0.782 NWeeding)
Key:
Y = dependent variable (number of leaves per plant)
R2 = coefficient of determination
X = independent variable (weeks after sowing)

Figure 5 - Linear relationship between number of leaves per plant and days after sowing as affected by method of weed control

providing avenues for plant to develop higher number of leaves per plant. The observed role of atrazine + paraforce as pre-emergent herbicide was previously reported (Amosun et al., 2021; Chojnacka et al., 2023).

During crop establishment, which is very sensitive to weed attack, maize plants under hand weeding as owing to less weed competition, can develop a high number of leaves per plant to capture available sunlight and maximize growth rates.

4. Conclusion

Mixture of atrazine with paraforce as pre-emergent weed control of maize is highly efficient than atrazine with 2.4-D. Also, maize variety BR 9928-5R-Y had less grain loss in respect to the overall effect of weeds on the maize varieties considered in this study.

Authors' contributions

MAM: developed the concept of the research and prepared the draft. SOA: supervised the research in the field and laboratory and edited the draft.

Acknowledgements

Authors recognized with appreciation the Teaching and Research Farms at the Obafemi Awolowo University (OAU), Ile Ife and Osun State University (UNIOSUN), Ejigbo campus for providing enabling environment to conduct the study.

Funding

This is study received no external funding.

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