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Management of weeds in summer maize (*Zea mays* L.) by pre and post emergence herbicides

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Abstract

Maize (*Zea mays* L.) is highly sensitive to weed infestation and management of weeds is the most difficult aspect of summer maize cultivation, leading to significant yield losses of maize fields. The lack of weed management in critical period of growth results in major losses. To address these issues, reducing actively growing weeds at various stages and improving the bio efficacy of herbicides is beneficial. In addition, due to the scarcity of farm labour and rising labour costs during crop growth, this study aims to investigate the impact of chemical weed management, specifically pre and post emergence herbicides, on maize. In this context, a study was conducted with 8 treatments viz., with 2 pre-emergence and 4 post emergence herbicides, as well as hand weeding and a weedy check (control), with each treatment replicated 3 times in randomized block design. The results revealed that weed density and weed dry matter were considerably lower and weed control efficiency was higher, with the application of Atrazine at 1 kg a.i. ha^{-1} as Pre-emergence (PEA). The highest treatment remained on par with Tembotrione + Atrazine (1:10) at 750 g a.i. ha^{-1} during 20 and 40 DAS as Post emergence (PoETA) compared to other treatments except for manual weeding (MW). The higher growth, yield attributes and grain yield were obtained with application of Atrazine at 1 kg a.i. ha^{-1} as Pre-emergence (PEA) application and the highest treatment was comparable with Tembotrione + Atrazine (1:10) at 750 g a.i. ha^{-1} during 20 and 40 DAS as Post emergence (PoETA) over other treatments. This paper relates to the SDG of UN 1, 2, 4 and 15.

Keywords

grain yield; maize; pre and post emergence herbicides; weed control efficiency; weed density; weed dry matter

Introduction

Maize (*Zea mays* L.) is gaining prominence as a replacement for rice due to its greater adaptability and ability to thrive in diverse cropping systems (1). In India it is cultivated 10 million hectares, with a production of 33.6 million tonnes and a productivity rate of 3349 kg ha^{-1} (2). Odisha alone accounts for 0.272 million hectares area with 0.869 million tonnes of production and 3194 kg ha^{-1} productivity (3). However, the delayed implementation of weeding in the critical phase of weed competition, led to a substantial loss of maize grain yield up to 83% (4). Typically, the critical phase for weed competition in maize extends up to 45 days after sowing (DAS) and weeds emerging beyond this period do not significantly affect maize grain yield (5). The early proliferation of dense weeds associated with their physiomorphological changes in root system adversely affected the maize growth due to increased competition for nutrients by weeds (6).

Despite recognizing the critical weeding period, timely weeding is often hindered by labour shortages. Consequently, alternative control methods, such as the timing and dose of the herbicide applications, are gaining traction (7). Notably, pendimethalin and atrazine are becoming popular herbicides for managing early weed infestation in maize. These herbicides inhibit seedling root development, but weeds already emerged from the soil remain unaffected.

Additionally, HPPD enzyme inhibitors like mesotrione, tembotrione and topramezone are gaining recognition for controlling emerged weeds during critical growth periods in maize (8, 9). These herbicides cause foliage bleaching through oxidative degradation of chlorophyll and other photosynthetic pigments in maize weeds (10). They are highly selective to maize due to the presence of the enzyme glutathione S-transferase (GST) (11). However, comparative evaluations between these 2 groups of herbicides for weed control in maize are limited. Therefore, the current study was undertaken to address this research gap.

Materials and Methods

An experiment was performed at 18.80 °N, 84.18° E and altitude (AMSL) of 89 m during the summer season of 2023. Throughout the crop growing season, the site received a total rainfall of 136.3 mm. The mean minimum and maximum temperature varied from 16.6 to 30 °C and 31.7 to 45 °C respectively. During the crop season, the mean monthly relative humidity in the morning and afternoon was 94.0% and 57.2% respectively. During crop season, the average sunshine hour was 7.5 h/day which was also found to be adequate in the experimental field. The experiment was arranged in a randomized Block Design (RBD) with 8 treatments, each replicated 3 times. The treatment details comprised of Pendimethalin at 1 kg a.i. ha^{-1} as Pre-emergence (PEP), Atrazine at 1 kg a.i. ha^{-1} as Pre-emergence (PEA) and Topramezone at 25.2 g a.i ha^{-1} during 20 and 40 DAS as Post- emergence (PoETR), Tembotrione at 120 g a.i. ha^{-1} during 20 and 40 DAS as Post-emergence (PoET), Tembotrione + Atrazine (1:10) at 750 g a.i. ha^{-1} during 20 and 40 DAS as Post- emergence (PoETA), Mesotrione + Atrazine at 750 g a.i ha^{-1} during 20 and 40 DAS as Post-emergence (PoEMA), manual weeding twice during 20 and 40 DAS (MW) and a weedy check (Control) (WC). The soil at the experimental site was a sandy loam with a slightly acidic reaction. The initial soil samples (0-15 cm) were analysed and noted low in terms of organic carbon percentage and availability of nitrogen in soil, while the phosphorus and potassium availability were observed to be medium in the soil. The crop was scheduled with recommended dose of fertilizer application (120-60-60 kg of N-P_2O_5-K_2O). The “VNR 4226” variety of maize was dibbled at a spacing of 60 cm x 25 cm on 11th February 2023. The herbicides were sprayed using a knap sack sprayer equipped with a flood jet (pre-emergence herbicide) and a flat fan nozzle (post-emergence herbicide) at a spray volume of 500 L/ha as specified in the treatment details. Observations on weeds were recorded at 30, 60 and 90 DAS using a 0.25 m^2 quadrate in each plot and it was transformed using square root transformation and analyzed statistically as recommended (12). The weed control efficiency was calculated using the results (13). Research findings recorded on various parameters were statistically analysed and the results were inferred using standard procedures (14).

Results and Discussion

The experimental field was infested with grasses, sedges and broad-leaved weeds which include *Digitaria sanguinalis, Dactyloctenium aegyptium, Cynodon dactylon, Echinichloa colona, Rottboellia cochinchinensis, Eragrostis unioloides, Brachiaria reptans, Chloris radiata, Diplotaxis muralis* among grasses; *Cyperus rotundus* and *Cyperus esculantus* among sedges and *Phyllanthus amarus, Parthenium hysterophorus, Euphorbia hirta, Amaranthus viridis, Diger amuricata* among broad leaved weeds.

At 30 and 60 DAS, the weed control efficiency with PoETA and PEA were comparable with MW at 20 and 40 DAS, which ranged from 70 to 87% at 30 DAS and 72 to 80% at 60 DAS (Table 1). It has been observed that the perfor-

Table 1. Effect of different herbicides applied before and after weed emergence on weed parameters of summer maize

Treatment	Weed density (No/m^2)		Weed dry matter (g/m^2)		Weed control efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
PEP	11.70^{d} (136.50)	14.82^{bcd} (220.09)	6.40^{d} (40.58)	8.08^{c} (65.22)	65.37^{c}	66.59^{bcd}
PEA	10.82^{d} (116.50)	13.07^{def} (171.17)	5.61^{e} (32.25)	7.14^{d} (50.90)	70.45^{bc}	74.05^{ab}
PoETR	15.48^{b} (239.07)	15.43^{bc} (237.83)	8.89^{b} (78.59)	8.58^{bc} (73.42)	39.33^{e}	63.89^{cd}
PoET	16.28^{b} (264.50)	16.05^{b} (257.83)	9.08^{b} (81.99)	8.88^{b} (78.61)	32.97^{e}	60.84^{d}
PoETA	8.97^{e} (80.50)	11.33^{f} (129.83)	4.46^{f} (19.42)	6.35^{e} (40.42)	79.47^{ab}	80.17^{a}
PoEMA	13.55^{c} (185.75)	11.93^{ef} (144.50)	7.64^{c} (57.90)	6.87^{de} (47.07)	52.43^{d}	77.94^{a}
MW	7.25^{f} (52.50)	13.64^{cde} (185.83)	3.92^{f} (15.05)	7.94^{c} (62.57)	86.55^{a}	71.76^{abc}
Weedy (Control)	19.91^{a} (396.50)	25.66^{a} (657.83)	10.36^{a} (106.91)	14.43^{a} (202.14)	0.00	0.00
S.Em.±	0.51	0.74	0.33	0.404	3.109	2.779
CD (P=0.05)	1.54	2.25	1.02	1.226	9.430	8.429
CV (%)	6.80	8.45	8.33	8.23	10.10	7.77

*Figures in parentheses are original values. The data on weed density and weed dry matter are subjected to square root transformation ($\sqrt{(X \pm 0.5)}$

mance of the crop is directly related to efficiency of weed control. The efficiency of weed control at 30 DAS was noted maximum with MW which was on par with PoETA at 60 DAS. Among the herbicide treatments, the highest percentage of weed control efficiency was noted for PoETA which was comparable with that of PoEMA and PEA at 60 DAS. The increase in plant height, LAI and dry matter accumulation was significantly higher with the application of PEA over PoETR, PoET, PoEMA, MW, weedy check (control) and was comparable with the application of PEP and PoETA applications. The higher weed density creates a condition that the maize plant has to compete for resources with weeds during its growth (15, 16). This impact of weed density might have reduced the plant height in maize. The reduced weed density leads to taller maize plants and vice-versa (Table 2). Low weed density improves the resource availability to maize plant, which leading to increase in plant height (7, 17).

It has been stated that PEA had a significant impact in controlling weeds, thereby resulting in lower weed density (18-20). Similarly, another study reported that the application of atrazine also results in lower weed density (21, 22). In case of post emergence herbicides, a previous study found that Tembotrione at 50 g ha^{-1} combined with atrazine 0.5 kg ha^{-1}, when applied at 15-20 DAS, resulted in significantly higher plant height (23). These evidences showed that the increased plant height in PEA and PoETA was due to better weed control, leading to lower weed density and higher weed control efficiency. Reduced weed competition in PEA, PoEMA and PEP might have helped the crop to grow more and accumulate higher crop dry matter and higher leaf area in the above treatments (Table 2), promoting greater photosynthate assimilation and consequently, higher dry matter production (24).

The weed density and weed dry matter had a negative correlation with grain yield, indicating that the grain yield decreases with an increase in density and dry matter of weed (Table 1). Since these two weed parameters were higher in PoETR, PoET and PoEMA than in PEA, PoETA and PEP applied plots, the grain yield was lower in the former treatments. The application of PEA statistically showed a marked increase in grain yield over other treatments except PoETA. The increase in grain yield with the application of PEA was 15%, 17%, 38% and 44% over PoETA, PEP, PoETR and PoEMA respectively (Table 3). Furthermore, the yield attributes had a positive correlation with grain yield, indicating that an increase in yield attributes due to less competition of weed in the latter 3 treatments led to high-

Table 2. Effect of different herbicides applied before and after weed emergence on growth attributes of summer maize

Treatments	Plant height (cm)				Leaf area index			Crop dry matter accumulation (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	At harvest
PEP	87^{a}	188^{a}	190^{ab}	229^{a}	2.3^{b}	3.1^{a}	4.1^{b}	135^{ab}	615.3^{ab}	1454.4^{ab}	1822^{a}
PEA	88^{a}	196^{a}	220^{a}	236^{a}	2.7^{ab}	3.4^{a}	4.7^{a}	137.2^{a}	664^{ab}	1532.0^{a}	1959.0^{a}
PoETR	71^{b}	162^{b}	170^{bc}	192^{b}	1.8^{c}	2.6^{b}	3.6^{c}	118.4^{bc}	530.1^{bc}	1257.2^{bc}	1588^{b}
PoET	53^{c}	124^{c}	138^{c}	150^{c}	1.2^{d}	2.1^{c}	2.8^{d}	99.4^{d}	438.2^{d}	1022.0^{cd}	1313^{c}
PoETA	86^{a}	190^{a}	208^{a}	233^{a}	2.4^{ab}	3.2^{a}	4.3^{ab}	136^{a}	630^{a}	1497^{a}	1892.1^{a}
PoEMA	70^{b}	158^{b}	169^{bc}	190^{b}	1.8^{c}	2.6^{b}	3.4^{c}	118^{bc}	529^{bc}	1203.2^{c}	1500.1^{bc}
MW	54^{c}	133^{c}	140^{c}	153^{c}	1.2^{d}	2.1^{c}	2.9^{d}	100.4^{cd}	442^{cd}	1046^{cd}	1323.3^{c}
Weedy (Control)	36^{d}	100^{d}	104^{d}	112^{d}	0.81^{e}	1.6^{d}	2.3^{e}	84.5^{d}	350^{d}	850^{d}	1076^{d}
S.Em±	4.76	7.70	10.30	12.04	0.10	0.14	0.15	5.7	34	72.25	77
CD (P=0.05)	14.43	23.35	31.24	36.53	0.31	0.45	0.47	17.21	103	219.16	233
CV (%)	12.09	8.51	10.66	11.16	10.33	9.23	7.64	8.45	11	10.05	9

Table 3. Effect of different herbicides applied before and after weed emergence on yield attributes and yield of summer maize

Treatments	Yield attributes					Grain yield (t/ha)	Stover yield (t/ha)
	Cob length (cm)	Cob girth (cm)	Number of rows per cob	Number of grains per row	100 grain weight (g)		
PEP	21.12^{a}	17.76^{bcd}	19.51^{a}	34.37^{ab}	23.67^{a}	5.58^{b}	11.98^{a}
PEA	22.78^{a}	18.87^{ab}	19.92^{a}	34.92^{a}	24.33^{a}	6.53^{a}	12.52^{a}
PoETR	17.26^{b}	14.90^{cd}	16.67^{ab}	29.85^{ab}	23.67^{a}	4.71^{c}	10.61^{ab}
PoET	13.16^{c}	11.03^{d}	13.32^{bc}	24.32^{c}	21.67^{a}	3.34^{d}	8.88^{bc}
PoETA	22.23^{a}	18.02^{a}	19.74^{a}	34.53^{ab}	24.17^{a}	5.70^{ab}	12.51^{a}
PoEMA	16.97^{b}	14.50^{a}	16.41^{ab}	29.61^{b}	22.50^{a}	4.54^{c}	9.79^{bc}
MW	13.28^{c}	11.54^{abc}	13.44^{bc}	24.74^{c}	22.00^{a}	3.63^{d}	9.17^{bc}
Weedy (Control)	9.44^{d}	8.16^{e}	10.10^{c}	19.51^{d}	21.33^{a}	2.39^{e}	7.73^{c}
S.Em.±	1.12	1.02	1.12	1.55	1.15	0.28	0.67
CD (P=0.05)	3.42	3.10	3.42	4.72	NS	0.85	2.03
CV (%)	11.47	12.37	12.10	9.31	8.73	10.74	11.17

er yield. It was observed that the yield attributes were higher with the application of PEA along with PoET, thereby increasing grain yield (25).

The MW treatment could not provide a grain yield comparable to that of PEP, PEA and PoETA due to lower yield attribute characters (Table 3). This may be due to early weed control in pre- emergence herbicides application which allowed the crop to grow better and produce higher yield attributes (26). As a result, the yield attributes were significantly higher in the latter three treatments than in MW and consequently, their yields were also higher than MW. This can be explained by the positive correlation of grain yield with yield attributes, indicating that any decrease in yield attributes reduces the yield of maize (Table 4). The lowest grain yield was obtained under the weedy check due to higher weed growth, resulting in poor dry matter accumulation, lower yield attributes and ultimately a lower yield compared to all other treatment.

Table 4. Correlation between weed, yield parameters and yield of maize as influenced by herbicides during summer season

Grain yield, kg /ha	Correlation	Significant
Cob length (cm)	0.989	**
Cob girth (cm)	0.992	**
Number of rows per cob	0.983	**
Number of grains per row	0.982	**
100 grain weight (g)	0.975	**
Weed density	-0.715	*
Weed dry matter	-0.752	*

**Correlation is significant at 0.01 level, *Correlation is significant at 0.05 level

Further analysis was performed to support the consistent correlation of grain yield with yield attributes, weed density and weed control efficiency, including heat map clustering, principal component analysis and network plot analysis. The heat map clustering shows that sorting of variables into 2 major clusters with a colour range (0-40; blue-red) (Fig. 1). The first cluster was further subdivided into 2 subclusters: one that includes T_1, T_2 and T_5 and other with T_3 and T_6. The entire cluster 1 was characterized by the highest yield and yield attributes and the lowest weed parameters. Dependent characters of yield attributes including cob length, cob girth, number of rows per cob, number of grains per row and seed index to grain yield showed a positive correlation with treatments in cluster 1. However, in cluster 2, there was less dependence of yield attributing characters on yield. A comparable positive correlation with yield was observed in the yield attributing characteristics of the subcluster 1 including T_2, T_1 and T_5 treatments. Similarly, the subcluster 2 of cluster 1 with T_3 and T_6 had comparable results of yield attributes and grain yield. On the other hand, cluster 2 was characterized by the lowest yield and yield attributes and the highest weed parameters, which was further divided into 2 subclusters. Sub cluster 1 of cluster 2 includes T_4 and T_7 while subcluster 2 of cluster 2 includes weedy check (control). The heat map clustering findings reveal that the attempts made in controlling weeds in some treatments were partially effective in controlling weeds as they are clearly separated from better weed control plots. These results support findings of a recent study, which reported that the applications of herbicides were clearly discriminated from each other in terms of effective weed control

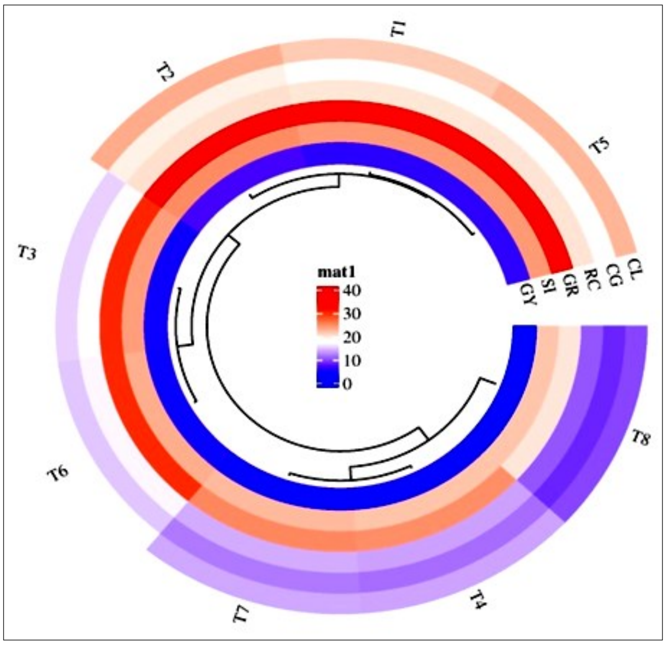

Fig. 1. Heat map clustering of different herbicide treatments. **T1**- PEP, **T2**- PEA, **T3**- PoETR, **T4**- PoET, **T5**- PoETA, **T6**- PoEMA, **T7**-MW, **T8**-Weedy (Control), **CL** – Cob length, **CG**- Cob girth, **RC**- Rows per cob, **GR**- grains per row, **SI** –seed index, **GY**- Grain yield.

(7).

Analysis of the network plot was performed to fortify the effect of individual treatments based on their performances on dry matter of weed at 30, 60 and 90 DAS (Fig. 2). In this, the nodes on the lines represent the strength of the relationships. The lighter line shows weaker relationship, while thicker line represents stronger relationships. The network plot showed a clear discrimination of weedy check (control) compared to other treatments. PEA was observed to have a strong correlation with PoETA, MW, the application of PoEMA and relatively weaker correlation with PoETR and PoET. Similarly, PoETA was found to have very strong correlation with MW and PEA, while its correlation with PoEMA was relatively weak and the weakest cor-

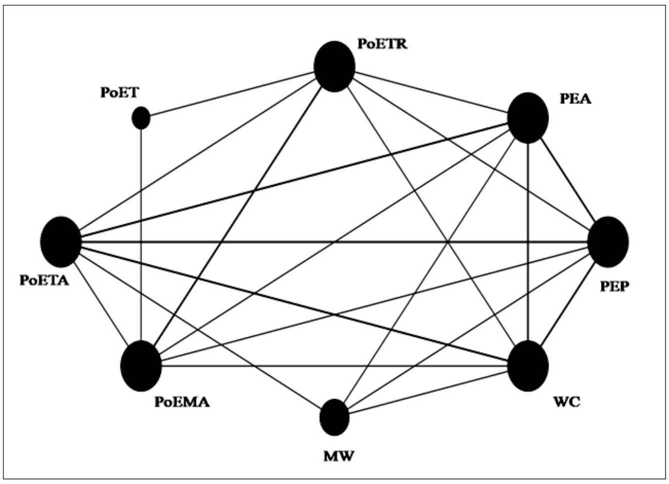

Fig. 2. Interaction between different herbicide treatments with respect to weed dry matter of maize.

relation was depicted with PoETR and PoET. This might be because of effective weed control by the application of PEA during the initial phase of maize growth through inhibition of radical establishment. Similarly, PoETA, being a strong HPPD enzyme inhibitor selective to maize crop, was reported to be highly effective in controlling weeds after crop emergence (8).

In this experiment, PCA showed that the variation was largely distributed in 2 components *viz.,* PC1 (80.46 %) and PC2 (14.06 %). This strong correlation between these components suggests that the biplot can effectively help assess how treatments affect all the parameters. PC1 showed positive associations with grain yield (t ha^{-1}), height of the plant, leaf area index and accumulation of dry matter (Fig. 3). The close alignment of vectors for these parameters suggests a strong positive correlation, which was influenced by the application of PEP and PEA treatments. On the other hand, PC1 exhibited negative correlations with weed dry matter and density. As the weed dry matter and density were higher in treatments PoETR and WC (control), these were present in the same quarter as that of weed dry matter and weed density.

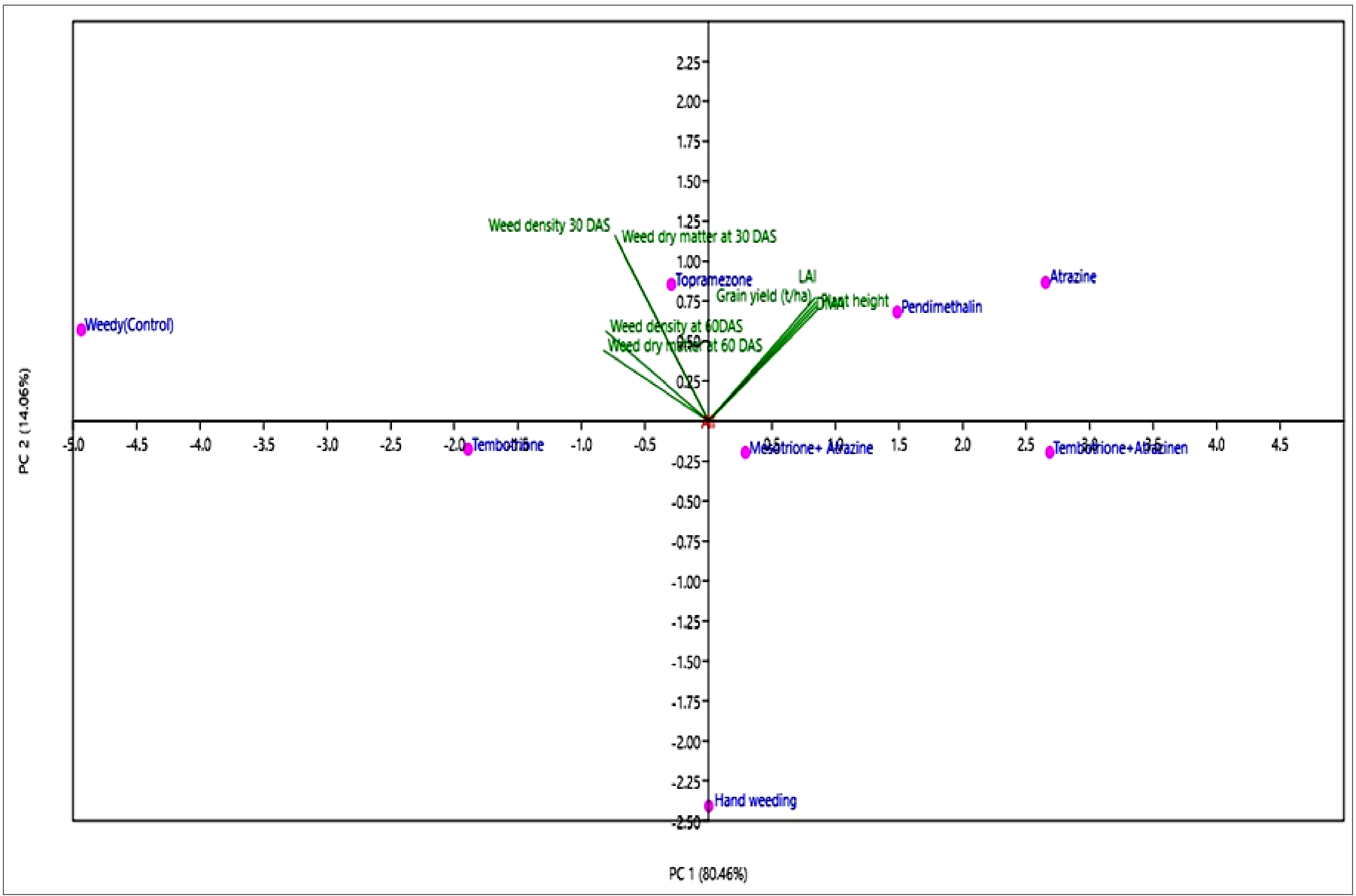

Fig. 3. Distribution of variation using principal component analysis.

Conclusion

Weed management through the application of Atrazine at 1 kg a.i. ha^{-1} as a Pre-emergence (PEA) treatment resulted in comparable weed density, dry matter and grain yield to that of Tembotrione + Atrazine (1:10) at 750 g a.i. ha^{-1} applied at 20 and 40 DAS as Post emergence (PoETA) treatment. These treatments produced higher grain yields compared to other treatments. Evaluating the efficiency of post emergence application of herbicides in maize crop during rabi season is necessary, as new post emergence herbicide molecules are continually being developed. Furthermore, this assessment is essential for adopting minimum tillage and in conservation agriculture practices such as rice fallow maize cultivation.

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Authors' contributions

SY carried out the field experiment and manuscript writing. LS and MDR contributed in statistical analysis and manuscript writing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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