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AGRONOMY

EVALUATION OF HERBICIDE EFFICIENCY AND THEIR IMPACT WITH REDUCED RATES ALONG WITH ADJUVANTS AT VARYING APPLICATION TIME IN MAIZE (*ZEA MAYS* L.)

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ABSTRACT

Herbicides are a major component of weed management in modern-day agriculture. A balanced dose of herbicides and an appropriate application time boost the growth and yield of the maize crop through efficient weed control. An experiment was performed at Agronomy Research Station, University of Agriculture, Faisalabad, in spring season 2021 and 2022 to assess the weed control efficiency of post-emergence herbicides applied at different doses alone and in combination with adjuvants at different timings during maize growth. There were two factors under study: herbicide doses [H_1= control, H_2= 25% reduced herbicide (Nicosulfuron Atrazine, and Propochar), H_3= 100% herbicide (Nicosulfuron, Atrazine, and Propochar), H_4= 25% reduced herbicide and combination with urea as adjuvant (Nicosulfuron, Atrazine, and Propochar), and H_5= 100% herbicide and combination with urea as adjuvant (Nicosulfuron, Atrazine, and Propochar) and application times i.e. 20 days after sowing (DAS), 30DAS, and 40DAS). The results showed that in comparison to weedy check, herbicide treatments resulted in significant decline in weed density, fresh and dry weight of weeds. The maize crop traits, including plant height, plant population, cob length, number of grains per cob, thousand-grain weight, grain yield, biological yield, and harvest index, also showed significant improvements. 100% herbicide and combination with urea as adjvant showed significant results in terms of morphological and yield-related attributes. Moreover, the application of full dose of herbicid combined with adjuvant (Nicosulfuron, Atrazine, and Propochar) produced better morphological and yield results as compared to other treatments. However, the application time of 20DAS comparatively produced better results than the other application times, i.e., 30DAS and 40DAS, regarding the morphological and yield-related attributes and weed flora.

KEYWORDS: *Zea mays:* adjuvant; herbicide control; herbicide efficacy maize; time of application; weed density; Pakistan

INTRODUCTION

Maize (*Zea mays* L.) is one of the most consumed cereals in Pakistan after rice and wheat, cultivated over one million hectares with an annual production of 9.8 million tonnes (GoP, 2024). Because of its widespread demand in modern industries, maize has become prominent in the agriculture-based economy. Improvements in maize yield thus is pivotal in stimulating the economic growth in agriculture. Poor planting procedures (Abbas *et al.,* 2020), suboptimal plant density (Anjum *et al.,* 2019; Waseem *et al.,* 2022), insufficient crop nutrients and irrigation (Hanif and Akhtar, 2020), pest attacks, and weed infestation are all factors that contribute to low maize production (Mubeen *et al.,* 2021). Among all the factors, weeds are the most damaging factor for the low yield of maize (Sharma and Rayamajhi, 2022). Weed infestation can reduce maize productivity by up to 20-30%, but can sometimes exceed 50% (Asif *et al.,* 2020). Throughout crop growth, weeds compete with crops for various resources (nutrients, water, space, and light) but the competition consequences vary at different growth phases. Weed-crop competition is minimal in the early phases of growth (Little *et al.,* 2021). Weed infestation not only lowers the yield but also decreases the overall profitability of a farming sector. Matloob et al. (2020) claimed that a 100% increase in maize yield could be achieved by prompt weed management. A significant loss to our nation's GDP results from weed infestation, which reduces the output of indigenous grains (wheat, rice, maize, sorghum, and bajra) by 3.4 million tonnes annually (Chovancova *et al.,* 2020).

Herbicidal effects result from various factors including weather, weed characteristics, application methods, herbicide concentration and interactions with other chemicals or adjuvants (Asif *et al.,* 2019) (Haliniarz *et al.,* 2018). The potency and persistence of the herbicide through the cuticle are increased when an adjuvant is used with it (Kasahara *et al.,* 2018). Because the effectiveness of herbicides on weeds typically depends on the kind of herbicide, the type of weed, the adjuvant chosen, environmental factors, thus choosing the right adjuvant for herbicides is challenging but crucial (Zhang *et al.,* 2022). Furthermore, different types and quantities of adjuvant chemicals, either integrated with designed products or their mixture, have been found to boost herbicide efficacy in various ways (Abbas *et al.,* 2021).Adjuvants can be utilized to improve herbicides' targeted efficiency by modifying spraying droplet formation, droplet entrapment and spray persistence on the surface of the leaf, as well as dispersion, penetration, and deposit formation (Kargar *et al.,* 2015). The herbicide composition, specifically the adjuvant systems can have a considerable impact on herbicide absorption within the plants (Hamouda *et al.,* 2021). To increase the effectiveness of weed control techniques and the use efficiency of applied herbicides during different weed-crop competition times, it is required to determine the extent, quantity, and patterns of herbicide application under such circumstances. (Geddes and Davis, 2021). Therefore, the following research was conducted to evaluate the reduced rate of herbicides alone and in combination with adjuvants at different times in maize growth and yield.

MATERIALS AND METHODS

Experimental site and planting material: The experiment was conducted to assess the reduced rate of herbicides alone and in combination with adjuvants at different time intervals on maize growth and yield. The research was carried out at the Agronomy Research trials station (31.25°N latitude, 73.09°E longitude, altitude 184 m), Department of Agronomy, University of Agriculture Faisalabad, Pakistan during 2021 and 22.

Experimental details: The recommended dose of herbicide Nicosulfuron 0.21 ml, Atrazine 2.16 ml, Propochar 1.62 ml and combination with urea as adjuvant is 17g.

There were two factors i.e. herbicide doses H_1= Weedy check (control), H_2= 25% reduced herbicide (Nicosulfuron 0.16 ml, Atrazine 1.62 ml, and Propochar 1.215 ml), H_3= 100% herbicide (Nicosulfuron 0.21 ml, Atrazine 2.16 ml, and Propochar 1.62 ml), H_4= 75% herbicide and combination with urea as adjuvant (Nicosulfuron 0.16 ml, Atrazine 1.62 ml, and Propochar 1.21 ml + 12 g urea), and H_5= 100% herbicide and combination with urea asadjuvant (Nicosulfuron 0.21 ml, Atrazine 2.16 ml, and Propochar 1.62 ml and17 g urea) and application times such as 20 days after sowing, 30-DAS, and 40-DAS). Randomized complete block design (RCBD) with two-way factorial was used by keeping three replications as shown in Fig. 1. All the crop husbandry practices i.e., land preparation, sowing, irrigation, fertilization, and harvesting were done uniformly throughout all treatments according to recommendations.

Meteorological data: Throughout the crop's growth, daily average data on minimum, maximum, and average temperatures, and average rainfall were recorded from metrological station of Agronomy, UAF and shown in Fig. 2

Observations:

Weed flora: The data regarding weed flora (Broad leave weeds) i.e., density, fresh and dry weight of weeds were recorded according to standard procedures. Weeds were randomly counted from one square meter in each plot and then the total number of weeds was calculated to record the weed density. The total fresh and dry biomass was calculated from the selected weeds of one square meter by weighing machine.

Morphological attributes: Different morphological attributes i.e., plant height, planting population, length

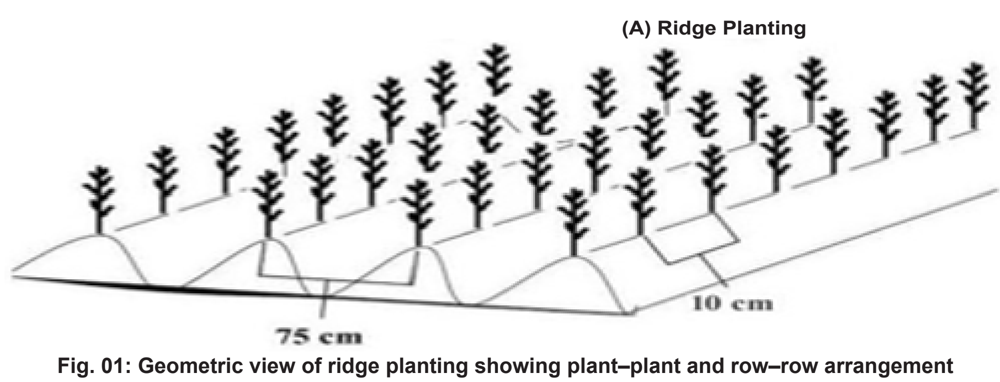

Fig. 01: Geometric view of ridge planting showing plant–plant and row–row arrangement

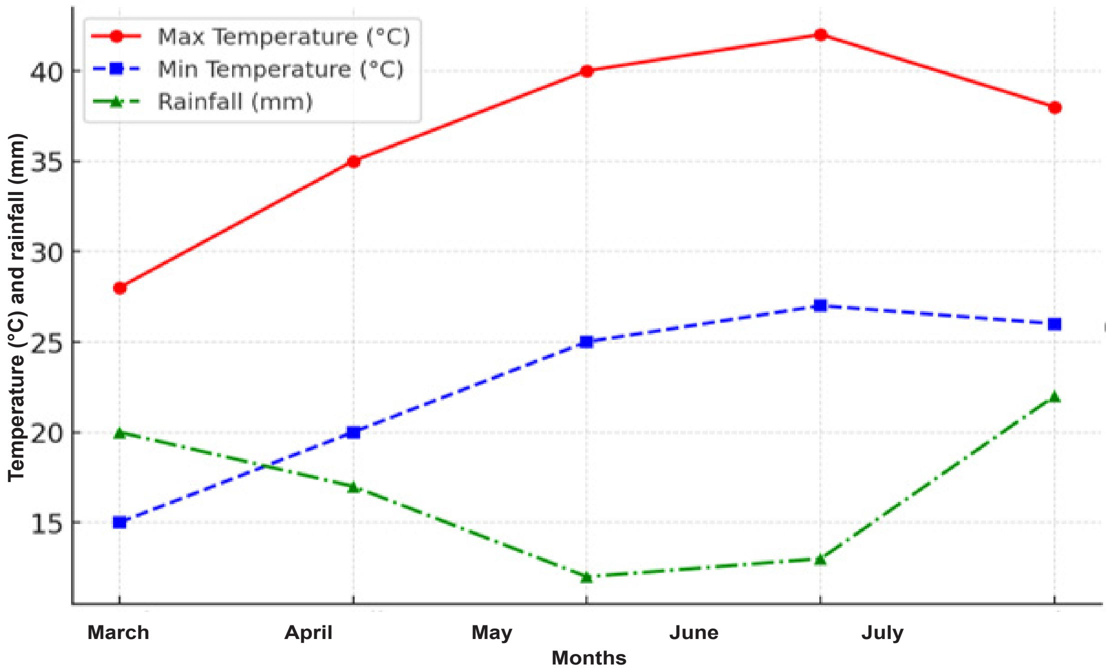

Fig. 2: Weather data showing maximum and minimum temperature with monthly rainfall during crop period.

of cobs, and number of grains per cob were recorded according to prescribed procedures. The plant height was calculated with a meter rod from the surface of the soil to the tip of the spike. The planting population is calculated by dividing the emerged seed by the total number of seeds sown and multiplying the product by 100 (Marschner *et al.,* 2024).

Emergence% = Total × 100

The cob length was calculated with a measuring scale. Furthermore, the average length was noted. After that, five cobs were chosen randomly in each treatment then threshed manually, and counted the total number of grains on cobs then divided by five to take the average number of grains per spike.

Yield and yield-related parameters: Yield and its related parameters were calculated according to standard procedures. Thousand gains weight was calculated with the help of a counting machine and their total weight was recorded with the help of an electrical weighing balance. After extracting the cobs from the harvest bundles, they were assessed again with a digital balance to determine the stalk yield per plot. The biological and grain yield was calculated for each plot after the threshing process with the help of electric balance in ton per hectare. The harvesting index was calculated by dividing the economical yield by the biological yield and then multiplied by 100.

Harvest index = Economical yield/ biological yield × 100

Statistical analysis: The “Statistics 8.1” program was used to calculate the differences of each treatment. Moreover, Tukey’s Honestly Significant Difference (HSD) at the significance level of 5% was treated to classify the significant values (Steel *et al.,* 1997).

RESULTS AND DISCUSSION

Weed flora: The data regarding weed flora attributes i.e., weed density, and fresh and dry weight of weeds showed significant variation ($P \leq 0.01$) in response to herbicide doses and application times (Table.1). The application time of 30DAS comparatively produced higher weed density and fresh weight of weeds than the other application times i.e., 20DAS and 40DAS. Among the herbicide doses. On the other hand, the control treatment recorded the highest number of weeds (184.33 m^{-2}), fresh weight of weeds (246.67g m^{-2}), and dry weight of weeds (133g m^{-2}). However, the dry weight of weeds showed higher results in 40DAS than other time intervals.

Morphological attributes: The data regarding morphological attributes such as plant height, plant populations, cobs’ length, No. of grain rows per cob, and No. of grains per cob showed significant variation in response to herbicide doses and application times shown (Table 2).

Among the herbicide doses, the application of 10.8 ml Nicosulfuron, Atrazine, and Propochar combined with adjuvant 17 g urea recorded the maximum plant height (141.00cm), and plant population (100%) after 30 and 20DAS, respectively. While the minimum plant height

Table.1: Effect of herbicide doses and time intervals on weed density (wd), fresh weight of weeds (fww), and dry weight of weeds (DWW) during 2021-2022

Factors	Weed density (WD)	Fresh weight of weeds (FWW)	Dry weight of weeds (DWW)
Application times (AT)			
20 DAS	102.27a	177.67a	80.733a
30 DAS	76.40b	167.07a	74.53b
40 DAS	94.00c	125.07b	65.20c
Herbicide doses (HD)			
Control	161.44a	267.33a	116.67a
75% Herbicide Alone	127.11b	204.56b	88.11b
100% Herbicide Alone	79.44c	125.44c	62.56c
75% Herbicide + Adjuvant	49.44d	99.89d	53.33d
100% Herbicide + Adjuvant	37.00e	85.78d	46.78e
Interaction (AT × HD)			
AT1 × HD1	193.67a	318.67a	133.67a
AT1 × HD2	135.00c	228.00c	93.67cd
AT1 × HD3	85.00e	140.33de	69.00f
AT1 × HD4	53.00f	108.67ef	59.33gh
AT1 × HD5	44.67f	92.67f	48.00ij
AT2 × HD1	128.33c	273.33b	114.33b
AT2 × HD2	110.33d	222.00c	89.33de
AT2 × HD3	72.33e	141.33de	65.67fg
AT2 × HD4	45.00f	108.67ef	52.33hi
AT2 × HD5	26.00g	91.33f	51.00hi
AT3 × HD1	162.33b	210.00c	102.00c
AT3 × HD2	136.00c	163.67d	81.33e
AT3 × HD3	81.00e	94.67f	53.00hi
AT3 × HD4	50.33f	83.67f	44.33ij
AT3 × HD5	40.33fg	73.33fs	41.33j

Significance (P < 0.05):

- **AT**: Significant for all parameters.
- **HD**: Significant for all parameters.
- **AT × HD**: Significant for all parameters.

Table.2: Effect of herbicide doses and time intervals on plant growth parameters

Factors	Plant height (PH)	Plant population (PP)	Cob's length (CL)	Grain rows per cob (NGRC)	Grains per cob (NGPC)
Application Times (AT)					
20 DAS	127.13a	87.78a	20.93a	16.13a	366.60a
30 DAS	123.08b	78.89a	20.26ab	15.73a	360.00ab
40 DAS	125.67ab	81.11a	18.80b	15.73a	352.60b
Herbicide doses (HD)					
Control	108.22a	72.22c	18.78b	14.22c	214.89e
75% Herbicide Alone	114.59b	79.63bc	18.56b	14.67c	347.89d
100% Herbicide Alone	127.18c	70.37c	18.11b	16.00b	380.11c
75% Herbicide + Adjuvant	137.83d	92.59ab	21.89a	17.11ab	406.11b
100% Herbicide + Adjuvant	138.66e	98.14a	22.67a	17.33a	449.67a
Interaction (AT × HD)					
AT1 × HD1	111.67e	83.33ab	18.67abc	14.00c	225.00i
AT1 × HD2	118.67de	83.33ab	20.00abc	15.33abc	358.67fgh
AT1 × HD3	128.67bc	72.22ab	19.00abc	16.67abc	384.00def
AT1 × HD4	139.67a	100.00a	24.00a	18.00a	406.67cd
AT1 × HD5	137.00a	100.00a	23.00abc	16.67abc	458.67a
AT2 × HD1	100.33f	55.56b	19.00abc	14.00a	227.33i
AT2 × HD2	112.75e	77.78ab	18.33abc	14.67bc	346.00gh
AT2 × HD3	126.67cd	77.78ab	18.67abc	15.33abc	387.67cde
AT2 × HD4	134.67abc	88.89ab	21.67abc	16.67abc	396.67cd
AT2 × HD5	141.00a	94.44ab	23.67ab	18.00a	442.00ab
AT3 × HD1	112.67e	77.78ab	18.67abc	14.67abc	192.33j
AT3 × HD2	112.34e	77.78ab	17.33bc	14.00c	339.00h
AT3 × HD3	126.22cd	61.11ab	16.67c	16.00abc	368.67efg
AT3 × HD4	139.14a	88.89ab	20.00abc	16.67abc	415.00bc
AT3 × HD5	137.97a	100.00a	21.33abc	17.33ab	448.00a

Significance ($P < 0.05$):

- **G**: Significant for all parameters except NGRC.
- **PT**: Significant for all parameters.
- **G × PT**: Significant for all parameters except NGRC.

(100.33) and plant population (55%) were recorded under the control treatment after 30DAS. However, the application of 8.1ml Nicosulfuron, Atrazine, and Propochar combined with adjuvant 12 g urea recorded the maximum cobs length (24.00cm) after 20DAS. Moreover, the No. of grain rows/cob and the No. of grains/cob produced better results (18) and (458) under the application of 10.8ml Nicosulfuron, Atrazine, and Propochar combined with adjuvant 17 g urea. On the other hand, the application time of 20DAS comparatively produced the highest cob's length, No. of grain rows/cob, and the number of grains/cob than other application times i.e., 30DAS and 40DAS. Weed density is considered the most crucial factor in weed-crop competition. Most studies reported weeds to hamper the growth and development of crops with weed density being the most important factor responsible for the low yield (Dongre and Singh, 2007). The type of weed species, weed density, weed length for competition, environmental factors, and management strategies all influence crop yield (Ali *et al.,* 2017). Weeds like *Cynodon dactylon* (L.), *Cyperus rotundus* (L), and *Trianthima portulacastrum* (L) mainly infest fall maize fields and cause significant production loss. Because the impact of one weed species tends to mask the impact of a subsequent weed species at significant weed density, a mixture of weeds had less impact than the total of their separate impacts (Fu and Ashley, 2006). According to a finding, the chlorophyll content of rice decreased with the increase of the weed density, whereas yield attributes of rice get reduced under high weed densities (Meher and Sunita, 2018) According to Romero *et al*. (2025), the application of an analogous emulsifier was the most successful in reducing the density of weeds and E. colona at all stages of observation in comparison to other herbicidal treatments. A study looked at the effectiveness of sorgaab aqueous extracts alone and in combination with the herbicide for suppressing weeds and densities of weeds in mungbean (Sarbout *et al.,* 2023).

Increasing weed density significantly increased the fresh weight of weeds and weed dry matter production. Shukla and Aditya (2020) indicated that the weed dry and fresh weights were significantly increased by increasing weed density. Shukla and Aditya (2020) showed that the dry weight of weed (*Scirpus maritimus*) in rice increased as its density level increased, which is consistent with our findings.

Grain production and economic productivity are impacted by weeds because they reduce the maize crop's ability to use all available resources for dry matter buildup. Weed infestation results in significant crop loss and yield reduction of up to 35% (Little *et al.,* 2021).

Plant height is one of the maize features that are thought to be essential in weed resistance to light. The maize plant's height during its life cycle shows its trend of biomass production. Herbicides showed no significant effect on the plant height of maize. However, the maize plant height was significantly influenced by the nitrogen levels, and the maximum plant height was measured under 120 and 150 kg ha^{-1} N levels (Majid *et al.,* 2017). The gradual reduction in maize plant height occured when *Parthenium hysterophorus* density rose might be because of increased interspecific competition between the crop and the weed for the same growth factors (Sarabi *et al.,* 2017). Numerous studies demonstrated the benefits of adjuvant-herbicide combos, demonstrating how the nature of biochemical processes might better and more consistently achieve herbicide efficacy (Pacanoski and Zvonko 2015). In addition, research results indicated that maize plant height decreased significantly when *P. hysterophorus* densities increased. The control condition, where no *P. hysterophorus* plants were able to compete with the crop, had the highest maize plants (Anwar *et al.,* 2021). According to a study, the season-long presence of weeds in a crop dramatically lowers plant height (Bayat *et al.,* 2021). The cob length of maize is a crucial element in determining yield. The number of grains per cob increased with increasing cob length, resulting in a higher yield of grains. The total grains' number per cob is influenced by cob length, which is to some extent correlated with the number of grains per row. An analysis of a study revealed that the application of herbicides considerably impacted the length of the maize cob, whereas nitrogen levels and the combination of herbicides and N levels had no significant impact on the length of the cob. The cob lengths produced by the three herbicides used to suppress weeds in maize were statistically comparable, but the atrazine-sprayed plots produced the longest cob length (13.25 cm), while the control plots produced the smallest (9.75 cm). The previous studies suggested that the herbicide treatment had a significant impact on the length of the maize cob, although the nitrogen levels and their interaction with the herbicide treatment showed no effect (Sajjad *et al.,* 2024).

Furthermore, Sharma *et al*. (2022) and Simić *et al*. (2020) revealed that the use of the proper weed control methods such as herbicidal weed control can promote the cob length in the maize crop. They predicted that the absence or diminished weed competition brought about by the herbicidal spray for weed management in the maize crop may have resulted in the N levels having no significant impact on the cob length of maize plants.

Cob weight and eventually grain output of maize have been directly impacted by the number of grain rows per cob. According to previous studies, appropriate weed control techniques are helpful in increasing the No. of grain rows/cob and as a result, yield would be increased (Quee *et al.,* 2020). Nedeljković *et al*. (2021) stated that the weed management techniques enhanced the number of grain rows on each cob.

An essential criterion for maize yield is the grains per cob. An earlier study revealed a substantial drop in grain output and grain counts when competing with the critical weed phase (Ayana, 2023) According to a study, the season-long presence of weeds in a crop dramatically lowers the number of grains per cob (Bayat *et al.,* 2021). It has been observed that keeping maize cropweed-free for 5–6 weeks after planting had no impact on the crop's production (Irungu and Esther Hugiru, 2021).

CONCLUSION

In conclusion, the study demonstrates the importance of optimizing herbicide doses and application timings in maize cultivation to achieve efficient weed control and enhance crop yield. The combination of a 100% herbicide (adjuvants (Nicosulfuron 0.21 ml, Atrazine 2.16 ml, and Propochar 1.62 ml) dose with adjuvant (17 g urea) applied at 20 days after sowing (DAS) proved most effective in reducing weed density and weight while significantly improving morphological and yield-related attributes of maize. These findings underline the potential of integrating reduced herbicide rates with adjuvants for sustainable agriculture. Furthermore, the study reinforces the importance of precise weed management during the early growth stages of maize to minimize resource competition and optimize productivity. This approach offers a pathway toward enhanced economic returns and efficient resource utilization in maize farming systems.

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