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Productive and qualitative indicators of forage yield of forage sorghum (*Sorghum bicolor* L.) varieties when controlling associated broadleaf weeds with 2,4-D 72% pre-emergence herbicide

Abdulmueen Shabeeb Hamad Al-Mafrajy *

Department of Medicinal and Industrial Plants, Collage of Medicinal and Industrial Plants, University of Kirkuk, Kirkuk, Iraq.

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Abstract

A field experiment was carried out during the spring season of 2023 in a farmer's field in the Kuldarah area of Altun Kopri district in Kirkuk Governorate, with the aim of knowing the effect of 2,4-D 72% herbicide on the growth of broad-leaved weeds accompanying the white corn crop, the dry and green fodder yield of this crop, and the qualitative traits in terms of the percentage of protein and fiber for six varieties of Sorghum (*Sorghum bicolor* L.) The experiment was applied according to the Randomized Complete Block Design (R.C.B.D.) with three replications, The treatments included (2,4-D herbicide, weed control and weed-free treatment, the varieties were (Buhuth - Giza - Rabeh - Lilo - Enqaz - J). The 2,4-D herbicide was sprayed before emergence using a (16) liter capacity continuous pressure backpack pump at a quantity of 1.5 liters. ha^{-1}, then it was mixed with the soil to prevent the light effect on the herbicide. The results of the statistical analysis indicated that spraying 2,4-D herbicide before emergence recorded the highest weed inhibition rate, reaching 79.111%, and the lowest weed index rate for green and dry fodder yields, reaching 9.742% and 24.637%, respectively, and an increase in the green and dry fodder yield, reaching 48.427 tons. ha^{-1} and 11.495 tons. ha^{-1}, respectively, the percentage of protein and fiber increased by 8.940% and 53.768% respectively. As for the varieties, the Bohouth variety was superior and recorded the highest weed inhibition rate of 30.889%. The Giza variety was superior in the weed index trait for dry fodder yield and recorded the lowest average weed index of 21.279%. The varieties (J, Giza and Bohouth) were superior in the green fodder trait and recorded 45.079, 44.860 and 44.103 respectively. The interaction coefficients between the study factors showed a noticeable variation in most of the studied traits, as the Bohouth variety combination was superior when controlled with 2,4-D 72% herbicide before germination in the inhibition rate trait and recorded the highest average of 92.667%, as well as the lowest percentage of weed index for dry fodder yield, which reached 10.550%. The dry fodder obtained It reached 13.476 tons. ha^{-1}, while in terms of qualitative traits, the combination of class (J) with 2,4-D herbicide was superior, as it recorded the highest average of 9.496%.

Keywords: Sorghum Bicolor L; Associated Weeds; 2,4; D Pesticide; Competition

1. Introduction

Sorghum (*Sorghum bicolor* L.) ranks as the fifth most important cereal crop globally, following wheat, rice, maize, and barley. It serves as a staple food for populations residing in semi-arid tropical regions. Despite its significant production potential, sorghum productivity remains relatively low due to various limiting factors, among which weed competition is a primary constraint, adversely affecting growth and yield. During the critical period, weeds reduced sorghum production by 15% to 40% (Mishra 1997). Sorghum is a staple food for over 500 million people in more than 30 countries. It has recently received significant attention not only because it is the fifth most important cereal crop, but

* Corresponding author: Abdulmueen Shabeeb Hamad Al-Mafrajy.

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also because it is an under-subsidized crop and its production potential is untapped. Sorghum could contribute to solving the food crisis, particularly for populations with increasing food needs (Lubadde *et al*, 2010). Weeds are one of the major problems facing agricultural production, as they act as a host for many insects and diseases, in addition to their negative impact in reducing the quantity and quality of the yield of many strategic crops, especially white corn (Swanton *et al*., 2015). Effective weed control is a critical factor in ensuring the success of soybean (*Glycine max* L.) production. To address this challenge, various weed management systems have been developed, aiming to minimize competition, enhance crop growth, and maximize yield potential) Sakar and Al-Mafrajy, 2023). Various methods have been used to combat weeds, the most prominent of which are chemical herbicides, which have replaced other control methods due to their high effectiveness and low cost. However, some of these herbicides, due to their continuous use, may lead to environmental pollution and may cause some damage to subsequent crops (Taha, 2000). The prevalence of diverse weed species, coupled with the rising occurrence of herbicide-resistant biotypes, constraints on crop rotation practices, and the limited availability of registered herbicides for sorghum cultivation, has collectively contributed to a complex and challenging environment for effective weed management in this crop (Peerzada *et al*., 2017; Simone Bartolini, 2018). The application of pre-emergence herbicides has been found to provide excellent and adequate weed control at the early stage of crop growth by reducing weed competition with the crop, leading to increased yield. Therefore, the interaction of weed control practices offers great potential in such a situation to achieve effective weed control combined with sound knowledge of different weed control practices (Thakur *et al*., 2016). A study conducted by Sharif *et al*., (2024a) indicated that the application of 2,4-D 72% pre-emergence herbicide to control broadleaf weeds resulted in a reduction in the number of weeds, the dry weight of broadleaf weeds, an increase in the control rate of this type of weeds, and a reduction in their competition with the crop, which was positively reflected in the vegetative growth traits. Therefore, this study aimed to evaluate the effectiveness of 2,4-D 72% herbicide when applied pre-emergence to the sorghum forage crop on the accompanying broadleaf weeds, as well as to evaluate the response of different varieties of the aforementioned crop to the control process using this method and to identify the variety with high forage productivity in terms of dry and green forage yield and its qualitative traits such as protein and fiber percentage.

2. Materials and methods

Koldara area of Altun Kopri district, within Kirkuk Governorate, Iraq. The experimental site is situated at a latitude of 35.65°N and a longitude of 44.37°E, approximately 23 km north of Kirkuk city. The objective of the study was to evaluate the effect of 2,4-D herbicide (72% concentration) on the suppression of broad-leaved weeds associated with sorghum (*Sorghum bicolor* L.), and its subsequent impact on both green and dry forage yield, as well as on certain qualitative traits, specifically crude protein and fiber content, across six sorghum genotypes.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatment structure included three weed management strategies: application of 2,4-D herbicide, a weedy control (untreated), and a weed-free control. The sorghum genotypes evaluated were: Buhuth, Giza, Rabeh, Lilo, Enqaz, and J.

Application of the 2,4-D herbicide was carried out prior to sowing using a backpack sprayer with a 16-liter capacity and continuous pressure system. The herbicide was applied at a rate of 1.5 L ha^{-1}, followed by incorporation into the soil to mitigate potential degradation from light exposure. Sorghum seeds were sown in rows using a seeding rate of 160 kg ha^{-1}. Row spacing was maintained at 50 cm, with 10 cm between individual plants within the row. Each replicate contains 18 experimental units with an area of (2*3 m^2 for the experimental unit, DAP fertilizer (46-18) was added when preparing the soil at an amount of 436 kg. ha^{-1}, and urea fertilizer was added at an amount of (696 kg. ha^{-1}) in two batches, one-third of the amount after the emergence was complete and the rest after 30 days of planting (Cheyed *et al*., 2014). The crop was harvested when the crop was fully mature.

2.1. The studied traits

Traits of weeds, including

2.1.1. Inhibition percentage %

- Inhibition ratio% = 100× A/B – 100 (Al-Chalabi, 2003).
- Where A: dry weight of weeds in the control treatment.
- B: dry weight of weeds in the comparison treatment.

2.1.2. weed index for green fodder crop%:

weed Index% = X - Y / X × 100 (Rana and kumar, 2014).

Where X = Yield from weed free, Y= Yield of a particular treatment.

2.1.3. Weed index to Dry Forage Yield%:

weed Index% = X - Y / X × 100 (Rana and kumar, 2014).

2.1.4. The traits of the product, which include

- Green fodder yield: One square meter was harvested from each experimental unit, the quantity was weighed and then calculated per hectare.
- Dry fodder yield: One square meter was harvested from each experimental unit and air dried, then its dry weight was taken and calculated on a per hectare.

2.1.5. Qualitative traits, including

- Protein percentage: The percentage of crude protein was calculated using the Micro kjeldal method according to (A.O.A.C., 1980).
- Nitrogen percentage (%) = Volume of HCL × Normal N × 0.014 × 2.5 / Volume of sample (g) × 100.
- Protein percentage (%) = Nitrogen percentage (%) × 6.25 (Cresser and Parssons, 1989).
- B- Percentage of fiber: Estimated using Tecator Fibertec 1010 Heat Extractor according to the method of (A.O.A.C., 1975).
- CF (%) = (weight of the pellet with the sample after drying - their weight after burning) ÷ weight of the sample × 100

Table 1 Types of weeds spread in the experimental field, their scientific and English names, family, and life cycle.

English name	**Scientific name**	**family**	**life cycle.**
Smeller Bind weed	*Convulus arrensis* L..	Convolvulacea	Biennial
Common Sow thistle	*Sonchus oloraceus* L.	Composite	Annual
Pureslane	*Portulaca oleraceae* L.	Partulacaceae	Annual
Wight goosefoot	*Chenopodium album* L.	Chenopodiaceae	Annual
Wild beet	*Beta vulgaris* L.	Chenopodiaceae	Annual
Rough Pigweed	*Amaranthus reteroflexus* L.	Amaranthaceae	Annual

2.2. Statistical analysis

The data under study were analyzed according to the analysis of variance and were statistically analyzed according to the randomized complete block design (R.C.B.D.) using the SAS statistical analysis program. The arithmetic means were compared using Duncan's multiple range test at a probability level of 5% (Hussain and Saleh 2019; Saleh and Hussain 2020), where the means that differed significantly from each other were distinguished by different letters.

3. Results and discussion

3.1. Types of Weeds

The Sorghum crop is one of the crops that are grown in two seasons. The experimental field was planted in the spring season and was accompanied by many broad-leaved summer weeds, which are mentioned in Table (1).

3.1.1. Weed traits

The effect of 2,4-D 72% herbicide and its varieties on the weed inhibition

3.1.2. ratio%

The control treatment that was not controlled with a pesticide or another method recorded the lowest weed inhibition rate compared to the treatment in which 2,4-D was used, reaching (0%) and 79.111, respectively (Table 2). This is attributed to the effectiveness of the pesticide when used before germination. As for the effect of the varieties, the Bahouth variety treatment recorded the highest weed inhibition rate compared to the other treatments, reaching

30.889%, which indicates the variety's response to control by this method of the herbicide, in which the herbicide inhibited seed germination and reduced its competition at that stage, which gave the variety an opportunity to respond and increase its competitive ability. This is consistent with what was mentioned by (Sharif *et al*. 2024a). As for the interaction between the study factors, the 2,4-D herbicide treatment with the Buhuth variety recorded the highest average percentage of inhibition, reaching 92.667 compared to the comparison treatment and other varieties, which indicates the great response of that variety to weed control.

Table 2 Effect of 2,4-D and fodder sorghum varieties on weed inhibition percentage (%)

Treatments	Varieties						
	Bohouth	**Giza**	**J**	**Rabeh**	**Lilo**	**Ingaz**	**Average herbicide effect**
2,4-D herbicide	92.667 a	67.667c	67.667c	82.333ab	81.333b	83.000ab	79.111 a
Weed control	0.00 d	0.00 d	0.00 d	0.00 d	0.00 d	0.00 d	0 b
Average effect of varieties	30.889 a	22.556b	22.556b	27.444ab	27.111ab	27.667ab	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

3.2. The weed index to green fodder crop

The results presented in Table 3 revealed statistically significant differences among the treatment means with respect to the weed index. The weed-free treatment recorded the lowest weed index value at 0%, indicating complete suppression of weed interference. This was followed by the treatment involving pre-plant application of 2,4-D herbicide, which resulted in a significantly lower weed index of 9.742%, compared to the untreated (weedy check) control that exhibited the highest weed index value of 53.433%. These findings emphasize that a lower weed index corresponds to improved crop yield potential, as the weed index serves as a quantitative indicator of yield loss due to weed competition.

Regarding the varietal effect on the weed index, the data showed no statistically significant differences among the sorghum varieties, as demonstrated in Table 3 (Xazaal & Raheem; Al-Jubouri et al., 2024). However, the interaction between weed management practices and sorghum genotypes revealed significant effects. Specifically, the Rabeh variety under herbicide treatment recorded the lowest mean weed index of 5.957%, which was statistically similar to the weed-free treatments across all varieties. This finding aligns with the observations reported by Rana and Kumar (2014), highlighting the potential of integrating resistant varieties with chemical weed control to optimize sorghum productivity.

Table 3 Effect of weed control with 2,4-D and forage sorghum varieties on weed index of green forage yield

Treatments	Varieties						
	Bohouth	**Giza**	**J**	**Rabeh**	**Lilo**	**Ingaz**	**Average herbicide effect**
2,4-D herbicide	14.090 d	11.793d	9.233 d	5.957 ed	9.113 d	8.267ed	9.742 b
Weed control	54.90ab	51.26bc	45.03c	51.83abc	57.86ab	59.70a	53.433 a
Weed free	0.00 e	0.00 e	0.00 e	0.00 e	0.00 e	0.00 e	0 c
Average effect of varieties	22.997 a	21.02a	18.089a	19.263 a	22.327a	22.656	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

3.3. Weed index for dry forage yield (%)

The data presented in Table 4 indicated the presence of statistically significant differences among the treatment means in relation to the weed index for dry forage yield. The application of 2,4-D herbicide prior to sowing resulted in the lowest weed index value, averaging 24.637%. This index represents the percentage ratio between the difference in dry forage yield between the weed-free and untreated (weedy) treatments, relative to the yield in the weed-free treatment, multiplied by 100. A lower weed index reflects reduced weed competition and consequently higher crop productivity.

With regard to varietal performance, significant differences were also observed among the sorghum genotypes. The variety *Giza* recorded the lowest weed index value at 21.279%, which did not differ statistically from the varieties *Buhouth*, *Rabeh*, and *Enqaz*, with respective values of 21.650%, 22.644%, and 23.211%. These results highlight the relative tolerance of these genotypes to weed interference and their potential to maintain forage yield under weed pressure. Furthermore, a significant interaction was detected between weed management practices and sorghum genotypes. Specifically, the *Buhouth* variety, when treated with 2,4-D herbicide before planting, achieved the lowest weed index value among the combined treatments. This could be attributed to the effective herbicide performance and the inherent vigor of the *Buhouth* genotype, which is characterized by enhanced vegetative growth and superior dry matter accumulation. These findings are in agreement with those reported by Rana and Kumar (2014), who emphasized the role of genotype-herbicide interactions in optimizing forage yield in sorghum cultivation.

Table 4 Effect of weed control with 2,4-D and forage sorghum varieties on weed index for dry forage yield

Treatments	Varieties						
	Bohouth	Giza	J	Rabeh	Lilo	Ingaz	Average herbicide effect
2,4-D herbicide	10.550 e	18.27de	31.667 c	23.90cd	41.40b	22.03b	24.637 B
Weed control	54.400 a	45.56ab	46.40ab	44.03b	44.96b	47.60ab	47.161 a
Weed free	0.000 f	0.000 f	0.000 f	0.000 f	0.000 f	0.000 f	0.00 c
Average effect of varieties	21.650 b	21.27b	26.02ab	22.64b	28.789a	23.211b	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

3.4. Green fodder yield (ton.h^{-1})

The results presented in Table 5 revealed significant differences among the treatment means with respect to green forage yield. The pre-plant application of 2,4-D herbicide resulted in the highest average green forage yield, reaching 48.427 tons ha^{-1}, compared to the untreated control treatment, which produced only 25.028 tons ha^{-1}. These findings confirm the effectiveness of 2,4-D herbicide in reducing weed interference and enhancing crop growth under field conditions. Regarding varietal response, the data indicated statistically significant differences among the sorghum genotypes. The variety *J* recorded the highest green forage yield, which was not significantly different from the varieties *Buhuth* and *Giza*, with average yields of 44.103- and 44.860-tons ha^{-1}, respectively. This superior performance may be attributed to the genotypes' favorable response to weed control, which likely promoted vigorous vegetative growth and biomass accumulation. These findings are in agreement with those reported by Sharif et al. (2024a), who emphasized the influence of genotype traits on forage productivity under weed management regimes. However, the interaction between herbicide application and sorghum varieties did not result in statistically significant differences, indicating a consistent response across genotypes in terms of green forage yield under herbicide treatment when compared to the untreated control.

Table 5 Effect of weed control with 2,4-D and forage sorghum varieties on green fodder traits

Treatments	Varieties						
	Bohouth	Giza	J	Rabeh	Lilo	Ingaz	Average herbicide effect
2,4-D herbicide	49.597 b	50.157 b	49.960b	46.647 b	48.193b	46.013 b	48.427 b
Weed control	25.503de	27.637cd	30.223c	23.017ef	19.783f	24.010def	25.028 c
Weed free	57.210 a	56.787 a	55.053a	49.560 b	54.993a	50.267 b	53.978 a
Average effect of varieties	44.103 a	44.860a	45.079a	39.741b	40.990b	40.097 b	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

3.5. Dry fodder yield (ton.h^{-1})

The data presented in Table 6 revealed statistically significant differences in dry forage yield as influenced by the herbicide treatments. The pre-plant application of 2,4-D herbicide resulted in the highest dry forage yield, reaching

11.495 tons ha^{-1}, significantly surpassing the untreated control, which recorded the lowest yield of 8.019 tons ha^{-1}. This improvement is likely attributed to the early suppression of broadleaf weeds, known for their highly competitive ability, thereby allowing the white forage sorghum crop to grow under reduced biotic stress. Such favorable growing conditions enhance both yield quantity and its components. These findings are consistent with those reported by Areej et al. (2022), who noted similar improvements in yield under early herbicide intervention. Regarding the effect of genotype, no statistically significant differences were observed among the six sorghum varieties with respect to dry forage yield, suggesting comparable performance under the conditions of this experiment. However, a significant interaction was observed between herbicide treatment and variety. Specifically, the *Buhouth* variety exhibited superior performance under the 2,4-D pre-emergence treatment, achieving a dry forage yield of 13.476 tons ha^{-1}. This suggests a favorable varietal response to weed suppression, likely linked to its vigorous vegetative growth and ability to capitalize on reduced competition during early developmental stages.

Table 6 Effect of weed control with 2,4-D and forage sorghum varieties on dry forage yield

Treatments	**Varieties**						
	Bohouth	**Giza**	**J**	**Rabeh**	**Lilo**	**Ingaz**	**Average herbicide effect**
2,4-D herbicide	13.476 b	12.256bc	10.336de	11.393cd	9.386ef	12.120bc	11.495 b
Weed control	6.986 g	8.163 fg	8.090 fg	8.306 fg	8.586 f	7.983 fg	8.o19 c
Weed free	15.070 a	15.100a	15.240a	15.133a	16.103a	15.613a	15.376 a
Average effect of varieties	11.844 a	11.840 a	11.222 a	11.611 a	11.358a	11.905 a	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

3.6. Protein percentage (%):

The results presented in Table 7 revealed significant differences in the protein percentage among the various treatments with 2,4-D herbicide application. The pre-plant treatment with 2,4-D recorded the highest average protein percentage at 8.940%, significantly higher than the untreated control, which had the lowest protein percentage of 6.787%. This increase may be attributed to the reduction in competition from broadleaf weeds, which are highly competitive for resources. By suppressing these weeds, the sorghum plants are able to better utilize available nutrients from the soil and environmental conditions, including water, which subsequently enhances growth and boosts photosynthetic efficiency.

Table 7 Effect of weed control with 2,4-D and fodder sorghum varieties on protein percentage (%)

Treatments	**Varieties**						
	Bohouth	**Giza**	**J**	**Rabeh**	**Lilo**	**Ingaz**	**Average herbicide effect**
2,4-D herbicide	8.903 ef	9.306 e	9.496df	8.256f	8.916 ef	8.763 ef	8.940 b
Weed control	6.493 g	6.926 g	6.913 g	6.783g	6.930 g	6.680 g	6.787 c
Weed free	10. 31c	11.09ab	10.17cd	11.16a	10.78abc	10.273cd	10.635 a
Average effect of varieties	8.570 b	9.110 a	8.86ab	8.73ab	8.877ab	8.572b	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

As a result, the protein content in the plants is significantly improved. These findings are consistent with those reported by Sharif et al. (2024b). Regarding the effect of varieties, the results of Table 7 indicated significant differences in protein content among the sorghum varieties. The Giza variety recorded the highest protein percentage at 9.110%, outperforming the other varieties. This superior protein content is likely linked to the genetic traits of the variety, as protein percentage is a qualitative trait influenced by genetic factors and its ability to respond to weed management strategies. This finding aligns with the observations of Sharif et al. (2024a), who noted the role of genetic traits in enhancing protein production. The interaction between herbicide application and sorghum varieties also showed significant differences. The J variety treated with 2,4-D herbicide before germination recorded the highest protein percentage at 9.496%. This increase can be attributed to the variety's favorable response to the herbicide, which reduced weed competition and allowed the plant to exhibit its superior traits, resulting in enhanced growth and protein content.

3.7. Fiber percentage (%)

The results presented in Table 8 indicated significant differences in fiber percentage among the different treatments with 2,4-D herbicide application. The control treatment exhibited the highest average fiber percentage at 53.768%, which was significantly higher than the 2,4-D treatment, which recorded the lowest average of 43.445%. This suggests that the herbicide effectively reduced the competitive capacity of broad-leaved weeds by enhancing the inhibition rate of these weeds, thereby improving the growth and quality of the forage yield, as demonstrated in Table 2. Regarding the effect of the varieties, the results in Table 8 revealed significant differences in fiber content among the sorghum varieties. The *Ingaz* variety recorded the highest average fiber percentage, reaching 57.863%, outperforming the other varieties that showed lower percentages. This highlights the variety's specific response to weed control measures and its distinct trait for higher fiber content, which is a qualitative characteristic intrinsic to the variety itself. As for the interaction between the study factors, the results showed significant differences among the treatment averages. The *Ingaz* variety demonstrated superior performance when subjected to the complete weed-free treatment, in which manual control was applied throughout the growing season. Under these conditions, *Ingaz* achieved the highest average fiber percentage of 61.333%, significantly outperforming all other varieties, including those treated with 2,4-D or the control treatment. This is in agreement with the findings of Sharif et al. (2024a), who observed similar trends in fiber content response under weed management practices.

Table 8 Effect of weed control with 2,4-D and fodder sorghum varieties on fiber persentage(%)

Treatments	**Varieties**						
	Bohouth	**Giza**	**J**	**Rabeh**	**Lilo**	**Ingaz**	**Average herbicide effect**
2,4-D herbicide	55.60cd	54.23cd	53.517d	53.367d	52.63d	53.26d	53.768 b
Weed control	40.900 e	42.513e	39.727ef	41.170e	37.36f	58.99ab	43.445 c
Weed free	58.50ab	58.81ab	58.83ab	56.50bc	59.86a	61.33a	58.974 a
Average effect of varieties	51,666 b	51.85b	50.69bc	5034bc	49.95c	57.86a	

Similar letters mean no significant differences between the means of the coefficients at the 5% level.

4. Conclusion

Based on the results of the current study, it was found that 2,4-D 72% herbicide has a high inhibitory effect on weed growth and can be used to eliminate harmful weeds and improve the productivity of cultivated plants.

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