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Evaluating the Efficiency of Barley Varieties, Weed Residues, and Their Interaction with Axial Herbicide Treatments in an Integrated Pest Management Program for Johnsongrass (*Sorghum halepense* L.) and Sunflower

Manal Ali Marai* and **Shaker Mahdi Saleh**

Department of Field Crops, College of Agriculture, University of Tikrit, Tikrit, Iraq

Corresponding author: **Manal Ali Marai** | E-mail: **Manal_ali@tu.edu.iq**

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Abstract

A field experiment was conducted in Al-Mu'tasim sub-district, Samarra district, Salah al-Din Governorate, during the 2025 growing season to evaluate the effect of three barley varieties (Arifat, Amal, and Samir), residues of two weed species (Sorghum halepense and Helianthus annuus), a control treatment with no residues, and their interaction with three treatments of the herbicide Axial (no herbicide, half the recommended amount, and the recommended amount) on weed density, control percentage, and dry weight, as well as on grain yield, biological yield, and harvest index for barley. The results showed that the recommended amount of herbicide was superior in reducing weed density and dry weight, and in achieving the highest control percentage of 93.3%, compared to the no-herbage treatment. The control treatment with no weed residues outperformed the treatments with wild thyme and sunflower residues in all studied traits, while the varieties differed significantly in grain yield, biological yield, and harvest index. The interaction of the three treatments showed a clear and significant effect on most traits. The results indicate the importance of integrating full-scale chemical control with weed residue removal within integrated weed management programs for barley crops.

Keywords: *Barley, Axial herbicide, weed residues, wild thyme, sunflower, integrated management.*

1.Introduction

Barley (Hordeum vulgare L.) is a strategic crop of importance in Iraq due to its diverse uses in food, fodder, and industry, and its relative tolerance to drought and salinity compared to other cereal crops. However, weeds are among the most significant biotic constraints on its production, competing with it for water, nutrients, light, and growing space, negatively impacting its vegetative characteristics and both quantitative and qualitative yield. Barley varieties differ in their competitiveness against weeds due to genetic variations in morphological and physiological traits such as germination rate, ground cover, plant height, root depth, and the rate of leaf area index development. This, in turn, affects weed density and dry weight among different varieties, ultimately impacting their final yield [1][2].

The impact of plant residues such as sorghum halepense and sunflower (*Helianthus annuus*) is increasing in the soil. These residues, as they decompose in the soil, can release various allopathic compounds, such as sorghum halepense and phenols [3], and helianthins and terpenes in the case of sunflower [4]. These compounds negatively affect the germination and growth of the subsequent crop, weaken its competitiveness, and alter the balance of competition between it and newly emerging weeds. Therefore, managing these residues is an essential part of any effective weed control program.

Chemical control using selective herbicides, such as Axial (active ingredient pinoxaden), is one of the most common and effective methods for controlling grassy weeds associated with barley crops. It works by inhibiting the acetyl-CoA carboxylase (ACCase) enzyme, which is responsible for fatty acid synthesis in susceptible grasses like barley. This inhibition halts their growth and leads to their gradual death without affecting the barley yield [5]. However, the effectiveness of this herbicide can be affected by several factors, most importantly the cultivated variety and its self-competitiveness, the presence of plant residues from previous weeds in the soil and the release of allelopathic compounds from these residues, and the dosage of the herbicide used (whether full or partial). This makes it essential to study these factors collectively rather than individually.

Chemical control using selective herbicides, such as Axial (active ingredient pinoxaden), is one of the most common and effective methods for controlling grassy weeds associated with barley crops. Given these data, the modern trend in weed management is moving towards integrated weed management programs that combine several approaches instead of relying solely on chemical control [1]. Among the most important of these approaches are: selecting the variety with the highest competitive ability against companion weeds, removing or treating existing weed residues to reduce their allelopathic effects, and optimizing the use of chemical herbicides at the appropriate dosage and timing. Wild thyme and sunflower are among the weeds that most necessitate this integrated approach due to their strong competition with barley crops and the persistence of their effects even after death through their decomposing residues in the soil.
Based on the above, this study aimed to evaluate the effect of three barley varieties, residues of wild thyme and sunflower, and three treatments of the herbicide Axial, as well as the interaction between these three factors on the characteristics of companion weeds and the growth and yield characteristics of barley crops, with the goal of identifying the optimal combination that achieves the highest control efficiency and the highest productivity.

2.Materials and Methods

1.2 Experimental Location and Factors

A field experiment was conducted in an agricultural field in Al-Mu'tasim sub-district, Samarra district, Salah al-Din Governorate, during the 2025 growing season. Barley was planted on November 15th. The experiment included three factors: the three barley varieties (Arifat, Amal, and Samir), the type of plant residues (sweet sedge residues, sunflower residues, and a control treatment with no residues), and the three Axial herbicide treatments (no herbicide, half the recommended amount, and the recommended amount.

2.2 Experimental Design and Experimental Units

The experiment was conducted using a randomized complete block design (RCBD) with a factorial arrangement. The varieties, residue types, and herbicide treatments were randomly distributed within each block, with three replicates per treatment. The experimental plot was prepared by plowing, harrowing, and leveling, and divided into equal-sized experimental units according to the experimental plan. Dried and ground sunflower or sedge residue was added to the soil before planting at the specified rate for each experimental unit, while the control units were left without any residue additions. Barley was planted using the three approved varieties, and Axial herbicide treatments were applied at the appropriate vegetative growth stage, according to the manufacturer's recommendations, at both half and full recommended doses. The no-application control was left untreated.

3.2 Studied Traits and Methods of Estimation

Thirty days after the application of the control treatments, the associated weed characteristics were estimated by taking random samples from each experimental unit. These included: weed density (number of weeds m^2), the percentage of control calculated from the percentage reduction in weed density compared to the weeded control treatment, and the dry weight of the weeds (g m^2) after drying the samples in an electric oven until the weight stabilized. Yield characteristics of barley plants at maturity were also estimated, including grain yield (kg ha^{-1}), biological yield (kg ha^{-1}), and harvest index (%) calculated as the ratio of grain yield to total biological yield.

4.2 Statistical Analysis

Data for all studied characteristics were statistically analyzed using a randomized complete block design with three intervening factors, employing the SAS statistical software. Means were compared using Duncan's multiple range test at a probability level of 0.05.

5.2 Soil Characteristics

Random soil samples were taken from the experimental field before planting, at a depth of 0–30 cm. These samples were air-dried, ground, and passed through a 2 mm sieve. Some of the physical and chemical properties of the soil were then determined in the laboratory of the Department of Soil Science and Water Resources at Tikrit University/College of Agriculture.

Table 1: Some physical and chemical properties of the experimental field soil

Property	Value
Sand (g kg^{-1})	535
Clay (g kg^{-1})	216
Silt (g kg^{-1})	249
Soil texture	Sandy clay loam
Total calcium carbonate ($CaCO_3$) (%)	23.00
Gypsum (%)	3.11
Available nitrogen (mg kg^{-1})	19.00
Available phosphorus (mg kg^{-1})	6.93
Available potassium (mg kg^{-1})	136.70
Soil pH	7.79
Electrical conductivity (EC) (dS m^{-1})	2.67
Cation exchange capacity (CEC) (cmolc kg^{-1})	17.89

4. Results and Discussion

4-1 Weed Density (plants/m^2) 30 Days After Treatment

The results in Table (2) show significant differences in weed density between varieties, pesticide treatments, and residue types. The Arifat variety recorded the highest average weed density at 11.1 plants/m^2, followed by the Amal variety with an average of 8.4 plants/m^2. The Samir variety did not differ significantly from the Amal variety. The superiority of the Arifat variety in weed density is likely attributed to its relatively weak competitiveness compared to other varieties, which allowed weeds a greater opportunity to grow and spread within its field. Studies indicate that a variety's competitiveness is influenced by morphological characteristics such as height, speed of soil coverage, and root depth [1].
Regarding the effect of herbicide treatments, the recommended application of Axial proved significantly superior in reducing weed density, registering the lowest average reduction of 2.2 plants m^2 compared to the no-herbicide treatment, which recorded 21.2 plants m^2.

This aligns with the finding [2] that full herbicide applications achieve the highest weed control rates associated with cereal crops compared to partial applications. Even half the recommended application resulted in a significant reduction of 5.9 plants m^2, indicating that the herbicide is effective even at reduced doses in reducing weed density.

Regarding the type of residue, sorghum halepense residues significantly increased weed density, averaging 15.8 plants m^2, higher than sunflower (Helianthus annuus) residues, which recorded 13.5 plants m^2. This can be explained by the fact that sorghum residues release chemical compounds that affect the growth of the main crop more than the weeds, thus weakening the crop's competitiveness and allowing the weeds to grow more. [3] and [4] confirmed that sorghum residues contain potent allelopathic compounds such as sorghum lactones and phenols, which inhibit crop growth and reduce their ability to compete with weeds.

Table 2: Effect of barley variety, type of plant residue, Axial herbicide treatment, and interactions between them on weed density (plants m^2) 30 days after application during the first season

Barley Cultivar	Residue Type	No Herbicide	Half Rate	Full Rate	Cultivar × Residue Mean
Arivat	Sunflower	31.6 c	9.3 fg	3.2 h	14.7 b
	Johnsongrass	38.2 a	11.2 f	6.4 g	18.6 a
	Control (weed-free)	0 i	0 i	0 i	0.0 d
Amal	Sunflower	24.3 e	6.1 g	1.6	10.7 c
	Johnsongrass	31.7 c	9.2 fg	3.0 h	14.6 b
	Control (weed-free)	0 i	0 i	0 i	0.0 d
Samir	Sunflower	35.4 b	7.6 g	2.8 h	15.2 b
	Johnsongrass	29.2 d	10.4 f	2.9 h	14.2 b
	Control (weed-free)	0 i	0 i	0 i	0.0 d
Herbicide Treatment Mean		**21.2 a**	**5.9 b**	**2.2 c**	**Cultivar Mean**
Cultivar × Herbicide	Arivat	23.3 a	6.8 c	3.2 d	11.1 a
	Amal	18.7 b	5.1 c	1.5 e	8.4 b
	Samir	21.5 a	6.0 c	1.9 de	9.8 b
Residue Type × Herbicide Mean	**Residue Type**	**No Herbicide**	**Half Rate**	**Full Rate**	**Residue Type Mean**
	Sunflower	30.4 b	7.7 d	2.5 e	13.5 b
	Johnsongrass	33.0 a	10.3 c	4.1 e	15.8 a
	Control (weed-free)	0.0 f	0.0 f	0.0 f	0.0 c

4-2 Control Rate (%)

The results in Table (3) show clear and significant differences in the control rate between the herbicide treatments. The recommended amount of Axial herbicide recorded the highest control rate at 93.3%, followed by half the amount at 82.0%, while the treatment without using the herbicide recorded only 33.3%, representing natural competition for the variety. The clear superiority of the full amount indicates the high chemical efficacy of Axial herbicide, which belongs to the acetyl-CoA carboxylase inhibitor (ACCase) group, a broad-spectrum herbicide effective against grassy weeds such as sedge and sunflower [5]. At the variety level, no significant differences were recorded between the three varieties in the average control rate, ranging between 68.3% and 70.3%, indicating the similarity of these varieties in their response to chemical treatments. However, the type of residue affected this characteristic, as the control treatment without weeds recorded the highest control rate (100%) across all herbicide treatments, confirming that the absence of native weeds is the optimal scenario for achieving production efficiency. These results are consistent with the findings [2] which showed that herbicide treatments achieved high control rates, reaching up to 89%, when using a combination of Lintur and Axial in barley.

Table 3: Effect of barley variety, type of plant residue, Axial herbicide treatments, and interactions between them on the percentage of control (%) after 30 days of application during the first season

Barley Cultivar	Residue Type	No Herbicide	Half Rate	Full Rate	Cultivar × Residue Mean
Arivat	Sunflower	0 h	70.6 g	89.9 c	53.5 bc
	Johnsongrass	0 h	70.7 g	83.3 d	51.3 c
	Control (weed-free)	100 a	100 a	100 a	100.0 a
Amal	Sunflower	0 h	74.9 f	93.5 b	56.1 b
	Johnsongrass	0 h	71.0 g	90.6 b	53.9 bc
	Control (weed-free)	100 a	100 a	100 a	100.0 a
Samir	Sunflower	0 h	78.6 e	92.1 bc	56.9 b
	Johnsongrass	0 h	72.3 fg	90.1 bc	54.1 b
	Control (weed-free)	100 a	100 a	100 a	100.0 a
Herbicide Treatment Mean		**33.3 c**	**82.0 b**	**93.3 a**	**Cultivar Mean**
Cultivar × Herbicide	Arivat	33.3 c	80.4 b	91.1 a	68.3 a
	Amal	33.3 c	82.0 b	94.7 a	70.0 a
	Samir	33.3 c	83.6 b	94.1 a	70.3 a
Residue Type × Herbicide Mean	**Residue Type**	**No Herbicide**	**Half Rate**	**Full Rate**	**Residue Type Mean**
	Sunflower	0.0 f	74.7 d	91.8 b	55.5 b
	Johnsongrass	0.0 f	71.3 e	88.0 c	53.1 b
	Control (weed-free)	100.0 a	100.0 a	100.0 a	100.0 a

4-3 Weed Dry Weight (g m^{-2}) : The results in Table (4) indicate a clear and significant effect of herbicide treatments on weed dry weight. The no-treatment treatment recorded the highest average dry weight of 29.77 g m^{-2}, while the recommended amount achieved the lowest average of 4.36 g m^{-2}, and half the recommended amount achieved 8.83 g m^{-2}. These results are consistent with what was indicated by [6] and [7] that allelopathic compounds secreted from weed residues increase their biomass in a way that negatively affects agricultural crops. Regarding varieties, the Arifat variety recorded the highest weed dry weight (16.08 g m^{-2}), consistent with its previously high weed density, while the Samir variety achieved the lowest dry weight (12.00 g m^{-2}), indicating its greater ability to inhibit weed growth and limit its biomass. Studies [8] and [9] confirmed that varieties with rapid soil cover and appropriate height suppress weed growth and significantly reduce their dry weight. The effect of residue type also varied significantly, with sunflower residues recording a higher weed dry weight (22.75 g m^{-2}) compared to hollyan residues (20.21 g m^{-2}). This is attributed to the different chemical nature of the allelopathic compounds in the two weeds. Sunflower compounds (such as helianthins and terpenes) may have a greater effect on the main crop than on the accompanying weeds, allowing the weeds to accumulate higher biomass [3].

Table 4: Effect of barley variety, type of plant residue, Axial herbicide application, and interactions between them on weed dry weight (g m^{-2}) 30 days after application during the first season

Barley Cultivar	Residue Type	No Herbicide	Half Rate	Full Rate	Cultivar × Residue Mean
Arivat	Sunflower	61.9 a	16.5 f	7.3 i	28.57 a
	Johnsongrass	40.3 d	12.2 gh	6.5 ij	19.67 cd
	Control (weed-free)	0.0 k	0.0 k	0.0 k	0.00 e
Amal	Sunflower	44.2 c	12.6 gh	5.5 j	20.77 c
	Johnsongrass	50.6 b	14.0 fg	7.0 i	23.87 b
	Control (weed-free)	0.0 k	0.0 k	0.0 k	0.00 e
Samir	Sunflower	38.6 d	11.3 h	6.8 ij	18.90 cd
	Johnsongrass	32.3 e	12.9 gh	6.1 ij	17.10 d
	Control (weed-free)	0.0 k	0.0 k	0.0 k	0.00 e
Herbicide Treatment Mean		**33.3 c**	**82.0 b**	**93.3 a**	**Cultivar Mean**
Cultivar × Herbicide	Arivat	34.70 a	9.57 c	4.60 d	16.08 a
	Amal	31.60 a	8.87 c	4.17 d	14.88 a
	Samir	23.60 b	8.07 c	4.30 d	12.00 b
Residue Type × Herbicide Mean	**Residue Type**	**No Herbicide**	**Half Rate**	**Full Rate**	**Residue Type Mean**
	Sunflower	48.23 a	13.47 c	6.53 d	22.75 a
	Johnsongrass	41.07 b	13.03 c	6.57 d	20.21 a
	Control (weed-free)	0.00 e	0.00 e	0.00 e	0.00 b

4.4 Grain Yield (ton ha^{-1})

Grain yield is the final result of all the preceding characteristics. The results in Table (5) indicate that the Samir variety had the highest average grain yield (4.03) tons ha^{-1}, followed by the Amal variety (3.96) tons ha^{-1}, and then the Arifat variety (3.82) tons ha^{-1}. This variation is explained by the genetic differences between the varieties in the efficiency of utilizing environmental resources and the efficient conversion of dry matter into economic yield [10;[11]. The recommended amount of Axial herbicide proved significantly superior, achieving the highest yield (4.17) tons ha^{-1} compared to half the amount (4.04) tons ha^{-1}) and the no-use treatment (3.60) tons ha^{-1}. This confirms the finding [2] that chemical weed control achieves a significant increase in grain yield by reducing losses due to competition with weeds. This result is also consistent with the finding [12] that uncontrolled weeds reduce grain yields by up to 30% under Iraqi agricultural conditions.

Table 5: Effect of barley varieties, type of plant residues, Axial pesticide treatments and interactions between them on total grain yield (kg ha^{-1}) after 30 days of control during the first season

Barley Cultivar	Residue Type	No Herbicide	Half Rate	Full Rate	Cultivar × Residue Mean
Arivat	Sunflower	3.16 j	3.77 h	3.89 fg	3.62 f
	Johnsongrass	3.22 j	3.80 gh	3.99 ef	3.67 ef
	Control (weed-free)	4.12 d	4.22 cd	4.19 c	4.18 b
Amal	Sunflower	3.25 ij	3.88 fg	3.94 ef	3.69 de
	Johnsongrass	3.30 i	3.81 gh	4.01 e	3.71 cd
	Control (weed-free)	4.41 b	4.50 ab	4.55 a	4.49 a
Samir	Sunflower	3.20 j	3.89 fg	4.11 d	3.73 c
	Johnsongrass	3.19 j	3.93 ef	4.26 c	3.79 c
	Control (weed-free)	4.53 a	4.59 a	4.61 a	4.58 a
Herbicide Treatment Mean		**3.60 c**	**4.04 b**	**4.17 a**	**Cultivar Mean**
Cultivar × Herbicide	Arivat	3.50 e	3.93 c	4.02 c	3.82 b
	Amal	3.65 d	4.06 c	4.17 b	3.96 a
	Samir	3.64 d	4.14 b	4.33 a	4.03 a
Residue Type × Herbicide Mean	**Residue Type**	**No Herbicide**	**Half Rate**	**Full Rate**	**Residue Type Mean**
	Sunflower	3.20 d	3.85 c	3.98 bc	3.68 c
	Johnsongrass	3.24 d	3.84 c	4.09 b	3.72 b
	Control (weed-free)	4.35 a	4.44 a	4.45 a	4.41 a

The control without weed residues had the most pronounced effect on yield improvement, yielding an average of 4.41 tons ha^{-1}, while the sunflower and oleander residue treatments recorded lower values (3.68 and 3.72 tons ha^{-1}, respectively). This result highlights the importance of removing weed residues from the field before planting or treating them to reduce their allelopathic effects. [1] and [13] concluded that decomposing weed residues in the soil significantly reduce grain yield by affecting germination, growth, flowering, and fertilization stages.

4-5 Harvest Index (%)

The harvest index represents the ratio of economic yield (cereals to total biological yield) and is an important measure of plant efficiency. Table (6) shows that the Samir variety recorded the highest harvest index (30.62%), followed by the Amal variety (30.26%), and then the Arifat variety (29.77%), with no significant differences in some comparisons. The superiority of the Samir variety in this trait is attributed to its high efficiency in transporting carbohydrates from the source (leaves and stems to the grain), a characteristic noted [15] as varying among varieties depending on their genetic makeup. The recommended herbicide application yielded the highest harvest index (31.09%) compared to half the application (30.32%) and the no-application treatment (29.23%). This significant result indicates that effective weed control not only increases overall yield but also improves the allocation of nutrients to the grain at the expense of other plant parts. This finding aligns with [16 ,17] the finding that the harvest index increases significantly when weed pressure on the crop is reduced. The no-residue control treatment recorded the highest harvest index (31.99%) compared to the sunflower and hollyhock residue treatments (29.13% and 29.52%, respectively). This decrease in the harvest index in the presence of weed residues suggests that allelopathic compounds inhibit The translocation of carbohydrates from vegetative plant organs to the grain leads to a decrease in the economic yield as a percentage of total biomass [18,19,20].

Table 6: Effect of barley variety, type of plant residue, Axial herbicide application, and interactions between them on the harvest index (%) 30 days after application during the first season

Barley Cultivar	Residue Type	No Herbicide	Half Rate	Full Rate	Cultivar × Residue Mean
Arivat	Sunflower	13.33 jk	13.79 hi	13.91 efg	13.68 de
	Johnsongrass	13.21 k	13.71 i	13.89 fgh	13.60 e
	Control (weed-free)	13.91 efg	14.11 d	14.22 cd	14.08 c
Amal	Sunflower	13.45 j	13.82 gh	14.01 de	13.76 d
	Johnsongrass	13.32 jk	13.80 ghi	13.99 ef	13.70 d
	Control (weed-free)	14.17 d	14.28 c	14.29 c	14.25 b
Samir	Sunflower	13.81 ghi	13.99 ef	14.17 d	13.99 c
	Johnsongrass	13.79 hi	13.93 ef	14.20 cd	13.97 c
	Control (weed-free)	14.32 c	14.49 b	14.64 a	14.48 a
Herbicide Treatment Mean		13.70 c	13.99 b	14.15 a	**Cultivar Mean**
Cultivar × Herbicide	Arivat	13.48 e	13.87 c	14.01 b	13.88 a
	Amal	13.65 d	13.97 bc	14.10 b	13.90 a
	Samir	13.97 b	14.14 b	14.34 a	14.15 a
Residue Type × Herbicide Mean	**Residue Type**	**No Herbicide**	**Half Rate**	**Full Rate**	**Residue Type Mean**
	Sunflower	13.53 d	13.87 c	14.03 b	13.81 b
	Johnsongrass	13.44 d	13.81 c	14.03 b	13.76 b
	Control (weed-free)	14.13 b	14.29 a	14.38 a	14.27 a

4- Conclusions and Recommendations

- Axial herbicide, applied at the recommended rate, achieved the highest efficiency in weed control and improved barley yield.
- Residues of wild clover and sunflower negatively impacted barley growth and yield.
- The Samir variety outperformed other varieties in most yield characteristics.
- It is recommended to use Axial herbicide at the recommended rate and remove weed residues before planting.
- Planting the Samir variety and implementing integrated weed management programs is recommended.

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