Effect of Soil Mulching and Irrigation Regimes on Morphophysiological Traits and Yield of Faba Bean (*Vicia faba L.*) Genotypes

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Abstract

This study aimed to evaluate the response of four fava bean genotypes (local, Spanish, Indian, and Turkish) to three soil mulching treatments (no mulching, rice husk, and black polyethylene) under two irrigation intervals (7 and 14 days). A field experiment was conducted during the 2025–2026 growing season at the College of Agriculture – Al-Qasim Green University, following a split-split plot arrangement in a randomized complete block design (RCBD) with three replicates. Genotypes were assigned to main plots, mulching treatments to subplots, and irrigation intervals to sub-subplots.

The results revealed significant differences between genotypes in all studied traits, with the Turkish genotype performing best in most of them [number of pods (32.34 pods/plant), 100-seed weight (174.31 g), plant yield (110.39 g/plant), and seed protein content (31.37%)]. Soil mulching also showed significant improvements in all studied traits compared to the control, except for harvest index. Irrigation period significantly affected all traits except 100-seed weight and number of seeds per pod. Meanwhile, the triple interaction between factors had a significant effect on all studied traits.

These results indicate that combining soil mulching with regular irrigation effectively helps improve morphophysiological performance and yield components of fava bean. Planting the Turkish genotype using soil mulching is recommended to ensure highest productivity under water shortage conditions.

Keywords: genotypes, *Vicia faba* L., soil mulching, rice husk, black polyethylene, irrigation.

Introduction

Faba beans (*Vicia faba L.*) Fabaceae are among the important legume crops worldwide because of their high nutritional value and economic importance. Their seeds are an important source of plant-based protein, carbohydrates, dietary fiber, minerals, and other nutrients, supporting their use in human and animal nutrition [20]. Faba beans are characterized by their high content of protein and essential mineral elements, making them an important crop for human nutrition and food security [13].

Genetic variation and diversity are the cornerstone in determining the productivity of the faba bean crop and its response to environmental variables, as genetic compositions differ in terms of vegetative growth traits, yield components, and the ability to adapt to environmental stresses [8]. Field evaluations of faba bean genotypes have demonstrated substantial variation in agronomic and yield-related traits, confirming the importance of genetic diversity in breeding and genotype selection [18].

The evaluation of these genetic architectures provides plant breeders with a valuable opportunity to incorporate them into breeding and improvement programs to develop new, high-yielding genetic architectures that are compatible with sustainable agricultural management systems and varying moisture levels in arid and semi-arid regions [16]. The screening

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and selection process relies on an understanding of the relationships between morphological and yield traits and on the use of genetic variation as an effective means of identifying genetically superior genotypes [8].

Fava beans are a crop that is relatively sensitive to soil moisture deficiency, particularly during reproductive development ، Water stress causes severe physiological and morphological disturbances that negatively affect the plant's metabolic pathways and reproductive processes ، Water deficit can also alter water-use characteristics and nutrient composition in faba bean genotypes, thereby affecting plant performance under stress conditions [19].

Regular irrigation intervals contribute to maintaining favorable soil-water conditions and improving crop productivity and water-use efficiency under water-limited conditions ، Different water regimes can result in substantial differences among faba bean genotypes in yield and physiological performance, highlighting the importance of appropriate irrigation management for maintaining productivity under water scarcity،This highlights the importance of studying irrigation intervals in water-scarce environments to identify water regimes that can maintain crop productivity while improving water-use efficiency [18].

Mulching is an important agricultural practice for modifying the soil environment by influencing soil moisture

Material and Methods

Experiment location and conditions

A field experiment was conducted during the 2025–2026 winter cropping season in the experimental field of the College of Agriculture, Al-Qasim Green University, Babil Governorate, Iraq. The aim was to study the response of four genotypes of faba beans (*Vicia faba L.*) to soil mulching and temperature conditions and consequently affecting crop growth and productivity، Plastic-film mulching can increase soil moisture and temperature and can improve crop yield and above-ground biomass in faba bean production systems [22].

Mulching materials range from organic to synthetic, with rice husks emerging as a promising agricultural by-product for use as a mulch material. Rice husks have a relatively resistant structure and slow degradation, which contributes to their persistence when used as an agricultural residue [17]. Rice-hull mulch has also been shown to suppress the germination of some weed species, demonstrating its potential as a physical weed-management material [4]. In addition, rice-derived products can exhibit allelopathic activity and may contribute to weed suppression through biologically active compounds [17].

On the other hand, the use of plastic mulch is an effective agricultural technique for modifying soil moisture and temperature conditions. Field research on faba bean has demonstrated that plastic-film mulching can increase soil moisture and soil temperature and can affect crop yield and above-ground biomass [22]. More recent field research has also demonstrated that plastic-film mulching modifies the soil hydrothermal environment in faba bean production systems, although its effect on yield may depend on the production environment and associated management practices [10].

treatments and irrigation intervals in relation to yield traits, yield components, and seed protein content. After preparing the soil, which included plowing, leveling, and smoothing, the experimental units were established according to the experimental design used in the study.

Soil and climatic characteristics

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Prior to planting, soil samples were collected from a depth of 0–30 cm to determine the physical and chemical properties of the experimental site. The soil was classified as clay loam, with a pH of (7.3), electrical conductivity (EC) of (2.20 ms.cm-1), organic matter content of (0.014), and available N, P, and K contents of (0.031), (0.009), and (0.02) mg/kg, respectively.

Experimental Design and Intervals

The experiment was conducted using a randomized complete block design (RCBD) arranged in a split-split plot design with three replications. The genetic arrangements were placed in the main plots, which included four genetic types: the local genotype (V1), the Spanish genotype (V2), the Indian genotype (V3), and the Turkish genotype (V4) The seeds used in the experiment exhibited a germination percentage of 90%. Soil mulching treatments consisted of three levels:

C0: No mulch (control).

C1: Soil mulched with rice husks, applied at a rate of 14 kg per experimental unit to a depth of 5 cm. The rice husks used were air-dried, obtained from(local rice mills in Al-Mishkhab district, Najaf Governorate, Iraq).

C2: Soil mulched with black polyethylene film of (0.05 mm)thickness, secured to the soil surface using soil-covered edges, with planting holes made at the designated spacing.

Irrigation treatments

Two irrigation intervals were applied:

R0: Irrigation every 7 days.

R1: Irrigation every 14 days.

Irrigation was applied using a surface irrigation system.

Thus, the experiment included 72 experimental units, with 24 units in each replicate. Each experimental unit had an area of 8.75 m², with dimensions of 3.5 × 2.5 m, and contained five planting rows. Ten plants were kept in each row according to the planting arrangement used in the experiment. The distance between rows was 50 cm and 30 cm between plants within a row. Buffer spaces of 1 m between sections and 0.5 m between experimental units were also maintained to minimize interference between adjacent intervals.

Crop cultivation and maintenance

The seeds were planted on October 25, 2025, with two seeds in each planting hole. Thinning was done three weeks after germination, leaving only one plant per hole. Regular crop maintenance, including weed control and irrigation management according to the specified intervals, continued throughout the crop growth period until reaching physiological maturity.

Yield Assessment and Its Components

When the plants reached the physiological maturity stage, five plants were randomly selected from the middle rows of each experimental unit to avoid the effects of the edge plants, and these plants were used to estimate the yield traits and their components.

Number of pods per plant

The number of pods per plant was determined by counting the mature and fully grown pods on the five selected plants from each experimental unit. Then the average number of pods was calculated and expressed as pods plant^{-1} .

Number of seeds per pod

The number of seeds per pod was determined by counting the seeds in the mature and fully grown pods taken from

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the selected plants. Then the average number of seeds per pod was calculated.

Weight of 100 seeds

The weight of 100 seeds was determined by randomly selecting 100 seeds from each experimental unit and weighing them using a sensitive scale. The results were expressed in grams.

Seed yield of the plant

Calculated based on the average dry seed yield per plant from randomly selected plants. The results were expressed in g plant^{-1}.

Harvest index

The harvest index was calculated using the following equation:

Harvest Index (%) = (Economic yield ÷ Biological yield) × 100

where the economic yield represents the seed yield, and the biological yield represents the total dry matter of the above-ground plant parts.

Protein content of seeds

The percentage of protein in faba bean seeds was estimated using the Lowry method according to [15]. Representative samples of seeds were collected from each experimental unit and prepared for analysis following the procedures of the method used, and the results were expressed as a percentage of protein (%).

Statistical Analysis

The data were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for a split-split plot design within a randomized complete block design (RCBD), using the GenStat statistical software. Means of the intervals were compared using the Least Significant Difference (LSD) test at a probability level of $P \leq 0.05$.

Results and Discussion

Table (1) showed a significant effect of genotypes on the trait of the number of pods per plant, as genotype V4 was statistically superior, yielding the highest mean of 32.34 pods plant^{-1}, whereas genotype V3 recorded the lowest mean of 17.47 pods plant^{-1}, representing an 85.12% increase. This variation is attributed to genetic differences among the genotypes in vegetative and floral growth efficiency, the regulation of fruit set, and spine formation, as well as differences in the root system's efficiency in absorbing and utilizing water and nutrients, which in turn affected the efficiency of transporting photosynthetic products to the terminal organs (flowers and pods) and reduced the rate of flower drop. [12] demonstrated that genetic variation among fava bean genotypes affects resource utilization efficiency and the formation of productive traits, including the number of pods per plant.

Irrigation intervals, the results showed a significant effect, with interval R0 recording the highest average of 24.17 pods plant^{-1}compared to interval R1, which recorded 20.39 pods plant^{-1} an increase of 18.54%. This is attributed to the fact that the regular supply of water to the plants maintained water potential and cellular turgor, allowing photosynthesis to continue without water stress that causes the shedding of flowers and newly formed pods. This is consistent with [5], who found that exposing fava beans to water stress reduces pollination and fertilization efficiency and leads to a reduction in the number of pods per plant.

The mulching treatments also showed a clear significant effect, as treatment C2 outperformed the others by yielding the highest average of 25.02 pods plant^{-1}, compared to treatment C1, which recorded 22.75 pods plant^{-1} a 9.98% increase—and compared to treatment C0, which recorded the lowest average of 19.07 pods plant^{-1},

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representing a 31.13% increase. This superior performance is attributed to the role of mulching, especially black polyethylene mulch, in mulching soil moisture, reducing evaporation, and regulating root-zone temperature, thereby providing a favorable environment for pod formation and development. This finding is consistent with [6], who reported that black plastic mulch improved faba bean yield components, including the number of pods per plant, compared with the un mulched control.

The interaction between irrigation intervals and mulching (RC), the effect was not significant, whereas the interaction between mulching and genotypes (CV) had a significant effect, with the C2V4 interaction yielding the highest mean of 39.23 pods plant^{-1}, while the C0V3 interaction recorded the lowest mean of 14.57 pods plant^{-1}, representing an increase of 169.25%.

Regarding the interaction between irrigation intervals and genotypes (RV), it was significant, with the R0V4 interaction recording the highest mean of 33.93 pods plant^{-1}, while the R1V2 interaction recorded the lowest mean of 16.44 pods plant^{-1}, representing an increase of 106.39%.

The interaction between irrigation intervals, mulching, and genotypes (RCV) was statistically significant, with the R0C2V4 interaction recording the highest mean of 39.93 pods plant^{-1}, while the R1V3C0 interaction gave the lowest mean of 13.80 pods plant^{-1}.

Table (2) showed a significant effect of genotypes on the number of seeds per pod, as genotype V3 performed significantly better, yielding the highest mean of 3.89 seeds pod^{-1}, while genotype V4 recorded the lowest mean of 2.03 seeds pod^{-1}, representing a 91.63% increase. This variation is attributed to genetic and morphological differences among the genotypes in the number of eggs formed and fertilized within the ovary, the efficiency of the pollination and fertilization systems, and genetic variation in the size and length of the ovary, which determines the capacity to accommodate the number of seeds formed. In this regard, [2] noted that seed number per pod is highly genetically controlled and varies depending on the genetic makeup and morphological structure of pods in fava beans.

Irrigation intervals, the results showed no significant effect, likely due to the number of seeds per pod. Mulching treatments showed a significant effect; treatment C1 outperformed the others, yielding the highest average of 3.54 seeds pod^{-1}, while treatment C2 recorded the lowest average of 2.97 seeds pod^{-1}, representing a 19.19% increase. The superiority of organic mulch may be attributed to its ability to conserve soil moisture and improve soil conditions, thereby creating a more favorable environment for reproductive growth and seed formation. Similar positive effects of straw mulching on the growth and yield performance of faba bean were reported by [14].

The interaction between irrigation intervals and mulching (RC), it was significant, with interval R0C1 recording the highest average of 3.59 seeds pod^{-1}, while R1C2 recorded the lowest average of 2.83 seeds pod^{-1}, representing an increase of 26.86%.

The interaction between irrigation intervals and genotypes (RV), the results were statistically significant, with the R0V1 interaction recording the highest average of 4.04 seeds pod^{-1}, followed by the R0×V3 interaction at 4.02 seeds pod^{-1}, on the other hand, R1V4 recorded the lowest mean of 1.87 seeds pod^{-1},

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representing an increase of 116.04%, which reflects the high genetic efficiency of genotypes V1 and V3 in utilizing water resources.

The interaction between mulching and genotypes (CV) had a clear significant effect, with the C1V1 interaction yielding the highest average of 4.55 seeds pod^{-1}; on the other hand, the C2V4 interaction recorded the lowest mean of 1.57 seeds pod^{-1}, representing an increase of 189.81%.

The interaction between irrigation intervals, mulching, and genotypes (RCV), it was significant, with the R0C1V1 interaction recording the highest mean of 4.72 seeds pod^{-1}, while the R0C2V4 interaction recorded the lowest mean of 1.52 seeds pod^{-1}.

Table 1. Effect of irrigation intervals, soil mulching, genotypes, and their interactions on the number of pods per plant (pods plant^{-1})

Irrigation R	Mulching C	Genotypes V				R×C
		V1	V2	V3	V4	
R0	C0	18.47	22.33	15.33	25.73	20.47
	C1	20.60	23.47	19.87	36.13	25.02
	C2	27.00	23.60	17.60	39.93	27.03
R1	C0	14.73	16.87	13.80	25.33	17.68
	C1	15.87	16.13	21.53	28.40	20.48
	C2	20.47	16.33	16.67	38.53	23.00
R×V		V1	V2	V3	V4	R
R0		22.02	23.13	17.60	33.93	24.17
R1		17.02	16.44	17.33	30.76	20.39
C×V		V1	V2	V3	V4	C
C0		16.60	19.60	14.57	25.53	19.07
C1		18.23	19.80	20.70	32.27	22.75
C2		23.73	19.97	17.13	39.23	25.02
V		19.52	19.79	17.47	32.34	22.28
LSD $_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
0.36	0.54	1.49	N.S	0.71	1.08	1.23

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Table (2): Effect of irrigation intervals, soil mulching, genotypes , and their interactions on the number of seeds per pod (seeds pod^{-1}).

Irrigation R	Mulching C	Genotypes V V1	V2	V3	V4	R×C
R0	C0	3.52	3.49	4.06	2.52	3.40
	C1	4.72	2.93	4.16	2.53	3.59
	C2	3.88	3.19	3.83	1.52	3.11
R1	C0	3.98	3.53	4.04	2.24	3.45
	C1	4.38	4.48	3.40	1.74	3.50
	C2	2.58	3.26	3.85	1.63	2.83
R×V		V1	V2	V3	V4	R
R0		4.04	3.20	4.02	2.19	3.36
R1		3.65	3.76	3.76	1.87	3.26
C×V		V1	V2	V3	V4	C
C0		3.75	3.51	4.05	2.38	3.42
C1		4.55	3.70	3.78	2.14	3.54
C2		3.23	3.23	3.84	1.57	2.97
V		3.84	3.48	3.89	2.03	3.31
LSD $_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
N.S	0.15	0.13	0.21	0.20	0.23	0.32

Table (3) showed a significant effect of genotypes on the 100-seed weight trait; Genotype V4 performed significantly better, yielding the highest mean of 174.31 g, compared to the other genotypes, with genotype V1 yielding the lowest mean of 142.75 g, representing an increase of 22.11%. This clear superiority of genotype V4 is attributed to differences among genotypes in their ability to transport photosynthetic products (carbohydrates and proteins) from sinks to sources and their filling capacity during the grain-filling phase, as well as the genetic variation governing seed size and specific gravity. This is consistent with [12], who reported high heritability for 100-seed weight in faba bean, indicating a substantial contribution of genetic variation to the expression of this trait.

The results showed no significant effect of irrigation intervals, indicating that variations in irrigation intervals did not significantly affect seed size and weight. The absence of a significant effect of irrigation intervals on 100-seed weight may indicate that the difference between the 7- and 14-day irrigation intervals was insufficient to cause substantial variation in seed filling and final seed weight under the conditions of the present experiment.

The mulching treatments also showed a significant effect, with treatment C2 yielding the highest average of 154.57 g, while C0 (control) recorded the lowest average of 147.56 g, representing a 4.75% increase. This effect may be attributed to the role of black polyethylene mulch in conserving soil moisture and modifying soil temperature, thereby providing favorable conditions for seed development during the seed-filling period. Similar positive effects of plastic film mulching on hundred-seed weight and yield

performance of faba bean were reported by [10].

The interaction between irrigation and mulching (RC), it was significant, with interval R0C2 recording the highest mean of 154.74 g, while the R1C0 interval recorded the lowest mean of 146.04 g, representing a 5.96% increase, indicating that the combination of regular irrigation and mulching ensures optimal water and nutrient supply to increase seed weight efficiency.

The interaction between irrigation intervals and genotypes (RV), the interaction was significant; the R0V4 interaction recorded the highest mean of 174.49 g, while the R1V3 interaction recorded the lowest mean of 141.42 g, representing a 23.38% increase, which confirms the high stability of the V4 genotype and the consistency of its seed weight regardless of the irrigation period applied.

The interaction between mulching and genotypes (CV) also had a significant effect; the C2V4 interaction stood out by yielding the highest mean of 180.19 g, while the C1V3 interaction recorded the lowest mean of 140.63 g, representing an increase of 28.06%.

The interaction between irrigation intervals, mulching, and genotypes (RCV), it was significant; the R1C1V4 interaction recorded the highest mean of 183.20 g, while the R1C1V3 interaction recorded the lowest mean of 139.30 g.

Table (3): Effect of irrigation intervals, soil mulching, genotypes , and their interactions on the weight of 100 seeds (g).

Irrigation R	Mulching C	Genotypes V V1	V2	V3	V4	R×C
R0	C0	141.12	143.17	141.45	170.55	149.07
	C1	143.99	146.27	141.95	173.58	151.45
	C2	144.13	144.51	150.99	179.33	154.74
R1	C0	140.29	145.38	140.33	158.16	146.04
	C1	142.41	139.91	139.30	183.20	151.21
	C2	144.53	147.33	144.64	181.05	154.39
R×V		V1	V2	V3	V4	R
R0		143.08	144.65	144.80	174.49	151.76
R1		142.41	144.21	141.42	174.14	150.55
C×V		V1	V2	V3	V4	C
C0		140.71	144.28	140.89	164.36	147.56
C1		143.20	143.09	140.63	178.39	151.33
C2		144.33	145.92	147.82	180.19	154.57
V		142.75	144.43	143.11	174.31	151.15
$LSD_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
N.S	0.87	0.90	1.34	1.41	1.55	2.24

Table (4) showed a significant effect of genotypes on plant yield, with genotype V4 yielding the highest average of 110.39 g plant^{-1}, while genotype V3 recorded the lowest average of 96.56 g plant^{-1}, representing a 14.32% increase. This variation is attributed to genetic differences among the genotypes in growth and production efficiency, as well as their ability to utilize water and nutrients and direct photosynthetic products toward yield components. These results are consistent with those of [18], who noted significant differences in bean yield due to differences in production efficiency and the distinctive genetic traits of each genetic type.

The results showed a significant effect of irrigation intervals, with the R0 irrigation interval recording the highest average of 109.39 g plant^{-1} compared to R1 irrigation (95.17 g plant^{-1}), representing an increase of 14.94%. This is attributed to the regular supply of water to the plants, which maintains water potential and cell turgor, allowing photosynthesis to continue without the plants being in water stress, which would have reduced yield and grain weight. [7] noted that exposure of legume crops to water stress reduces nutrient uptake efficiency and leads to a sharp decline in final plant yield.

The mulching treatments also showed a significant effect, as mulch treatment C1 outperformed the others by yielding the highest average of 112.36 g plant^{-1}, compared to mulch treatment C2, which recorded 102.34 g plant^{-1}, representing an increase of 9.79%, and compared to the control interval C0, which recorded the lowest average of 92.14 g plant^{-1}, representing an increase of 21.95%, This superiority of organic mulch may be attributed to its role in conserving soil moisture, improving soil conditions, and enhancing nutrient cycling, thereby providing more favorable conditions for crop growth and yield formation. Similar positive effects of organic mulching on faba bean productivity and soil conditions were reported by [21].

The interaction between irrigation intervals and mulching (RC) had a significant effect, with the R0C1 interaction recording the highest mean of 120.63 g plant^{-1}, while the R1C0 interaction recorded the lowest mean of 84.09 g plant^{-1}, representing an increase of 43.45%.

As for the interaction between irrigation intervals and genotypes (RV), it was significant, with the R0V1 interaction recording the highest mean of 115.33 g plant^{-1}, while the R1V2 interaction recorded the lowest mean of 88.44 g plant^{-1}, representing a 30.41% increase.

The interaction between mulching and genotypes (CV) also had a significant effect, with the C1V4 interaction yielding the highest mean of 120.10 g plant^{-1}, while the C0V3 interaction recorded the lowest mean of 82.83 g plant^{-1}, representing a 44.99% increase.

The three-way interaction between irrigation intervals, mulching, and genotypes (RCV) was also significant, with R0C1V1 yielding the highest average, while the R1C0V3 interaction recorded the lowest average of 78.00 g plant^{-1}.

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Table (4): Effect of irrigation intervals, soil mulching, genotypes, and their interactions on crop yield (g)

Irrigation R	Mulching C	Genotypes V				R×C
		V1	V2	V3	V4	
R0	C0	91.67	111.33	87.67	110.13	100.20
	C1	140.00	100.33	117.33	124.87	120.63
	C2	114.33	108.67	101.67	104.67	107.34
R1	C0	82.00	86.67	78.00	89.67	84.09
	C1	98.67	100.33	102.00	115.33	104.08
	C2	100.67	78.33	92.67	117.67	97.34
R×V		V1	V2	V3	V4	R
R0		115.33	106.78	102.22	113.22	109.39
R1		93.78	88.44	90.89	107.56	95.17
C×V		V1	V2	V3	V4	C
C0		86.83	99.00	82.83	99.90	92.14
C1		119.33	100.33	109.67	120.10	112.36
C2		107.50	93.50	97.17	111.17	102.34
V		104.55	97.61	96.56	110.39	102.28
$LSD_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
4.54	1.19	1.45	3.62	3.42	2.40	4.08

Table (5) showed a significant effect of genotypes on the harvest index trait, as genotype V2 performed significantly better, yielding the highest mean of 50.04%, while genotype V4 recorded the lowest mean of 38.53%, representing an increase of 29.87%. These differences may be related to genetic variation among faba bean genotypes in yield formation and biomass partitioning. [9] reported significant variation among faba bean inbred lines in yield and yield-related traits.

The irrigation intervals showed that R1 recorded the highest average (45.86%) compared to interval R0, which recorded 42.69%, representing an increase of 7.42%. The relatively higher harvest index under the longer irrigation interval may be associated with the reduction in vegetative growth under limited water availability, resulting in a relatively greater proportion of biomass being allocated to seed production. [7] reported that drought effects on legume yield vary according to species and phenological stage, with yield reductions generally being greater when drought occurs during the reproductive stage.

The mulching treatments did not show a significant effect on harvest index, indicating that the relative partitioning of biomass between vegetative growth (biological yield) and seed yield (economic yield) remained relatively stable among the mulching treatments, resulting in no significant differences in harvest index.

The interaction between irrigation intervals and mulching (RC), it was significant, with the R1C0 interaction recording the highest value of 47.75%, while the R0C0 interaction recorded the

lowest value of 41.10%, representing an increase of 16.18%.

The interaction between irrigation intervals and genotypes (RV) was significant, with the R1V2 interaction recording the highest average of 50.59%, while the R0V4 interaction recorded the lowest average of 37.73%, representing an increase of 34.08%

The interaction between mulching and genotypes (CV) also had a significant effect, with the C0V2 interaction yielding the highest mean of 51.00%; on the other hand, the C2V4 interaction recorded the lowest mean of 36.81%, representing an increase of 38.55%.

The interaction of irrigation intervals, mulching, and genotypes (RCV) was significant, with the interaction R1C2V3 recording the highest value of 56.17%, while the interaction R0C2V4 recorded the lowest value of 34.67%.

Table 5: Effect of irrigation intervals, soil mulching, genotypes , and their interactions on the harvest index (%).

Irrigation	Mulching	Genotypes V				R×C
R	C	V1	V2	V3	V4	
	C0	39.24	48.10	39.19	37.86	41.10
R0	C1	46.56	46.41	45.07	40.66	44.68
	C2	37.74	53.98	42.83	34.67	42.31
	C0	47.68	53.91	48.96	40.45	47.75
R1	C1	42.72	55.03	42.03	38.62	44.60
	C2	42.96	42.83	56.17	38.94	45.23
R×V		V1	V2	V3	V4	R
R0		41.18	49.50	42.36	37.73	42.69
R1		44.45	50.59	49.05	39.34	45.86
C×V		V1	V2	V3	V4	C
C0		43.46	51.00	44.07	39.15	44.42
C1		44.64	50.72	43.55	39.64	44.64
C2		40.35	48.40	49.50	36.81	43.77
V		42.82	50.04	45.71	38.53	44.27
$LSD_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
2.47	N.S	1.04	2.05	1.93	1.96	2.86

Table 6 showed a significant effect of genotypes on seed protein content, with genotype V4 performing significantly better by yielding the highest mean of 31.37%. Genotype V2 recorded the lowest mean of 26.12%, representing an increase of 20.10%. This superior performance of genotype V4 is attributed to differences in the genotypes' efficiency in nitrogen uptake and utilization, as well as the high capacity of its roots to biologically fix atmospheric nitrogen and direct metabolic and protein products toward the seeds during the grain-filling stage. This variation may be attributed to genetic differences among faba bean genotypes in nitrogen acquisition, utilization, and seed protein accumulation. [1] reported

significant genotypic variation in seed yield and protein content among faba bean genotypes grown under different water regimes.

The results showed a significant effect of irrigation intervals, with interval R0 gave the highest average protein content (28.81%) compared to interval R1, which recorded 28.16%, representing an increase of 2.31%. The higher protein content under the shorter irrigation interval may be attributed to the more favorable soil-water conditions, which supported physiological activity and nitrogen assimilation during seed development. In contrast, [3] reported an increase in seed protein content under water-deficit conditions in some faba bean genotypes. This difference from the present results may be attributed to variations in genotype, environmental conditions, severity and timing of water stress, and the duration of the irrigation intervals.

The mulching treatments also showed a significant effect, with treatment C2 yielding the highest average at 30.74%, while the bare soil control (C0) recorded the lowest average at 26.81%, representing an increase of 14.66%. The superiority of black polyethylene mulch may be attributed to its role in improving soil moisture and modifying the soil thermal environment, thereby providing more favorable conditions for plant growth and seed development. Similar effects of plastic-film mulching on soil moisture and temperature conditions and faba bean productivity were reported by [10].

The interaction between irrigation intervals and mulching (RC) had a significant effect, with interval R0C2 recording the highest average of 31.40%, while interval R1C0 recorded the lowest average of 26.76%, representing an increase of 17.34%, which demonstrates the protective role of plastic mulch in preserving protein content even under infrequent irrigation.

The interaction between irrigation intervals and genotypes (RV) had a significant effect, as the R0V4 interaction recorded the highest protein content of 32.48%, while the R1V2 interaction recorded the lowest average of 25.76%, representing an increase of 26.09%, which confirms the stable genetic superiority of the V4 genotype in protein synthesis across different levels of water availability.

The interaction between mulching and genotypes (CV) also showed a statistically significant effect, with the C2V4 interaction yielding the highest mean of 33.42, while the C0V2 interaction recorded the lowest percentage of 24.82%, representing an increase of 34.65%. The high response of the V4 genotype to plastic mulching was evident in the concentration of protein components within the seed.

The interaction between irrigation intervals, mulching, and genotypes (RCV) was highly significant; the R0C2V4 interval recorded the highest average protein content of 34.42%, while the R1C0V2 interaction recorded the lowest average of 23.74%, indicating that the combined effect of frequent irrigation and black polyethylene mulching maximizes the genetic potential of genotype V4 for protein accumulation in the seeds.

Table (6): Effect of irrigation intervals, soil mulch, genotypes, and their interactions on protein content (%).

Irrigation R	Mulching C	Genotypes V				R×C
		V1	V2	V3	V4	
R0	C0	25.57	25.90	27.13	28.84	26.86
	C1	26.23	25.34	26.97	34.19	28.18
	C2	30.85	28.23	32.10	34.42	31.40
R1	C0	26.02	23.74	29.56	27.71	26.76
	C1	26.12	26.13	27.72	30.64	27.65
	C2	28.96	27.41	31.53	32.42	30.08
R×V		V1	V2	V3	V4	R
R0		27.55	26.49	28.74	32.48	28.81
R1		27.03	25.76	29.61	30.26	28.16
C×V		V1	V2	V3	V4	C
C0		25.80	24.82	28.35	28.28	26.81
C1		26.17	25.73	27.35	32.41	27.92
C2		29.90	27.82	31.82	33.42	30.74
V		27.29	26.12	29.17	31.37	28.49
$LSD_{0.05}$						
R	C	V	R×C	R×V	C×V	R×C×V
0.14	0.14	0.15	0.18	0.20	0.26	0.36

Conclusion

The findings of this study confirmed that fava bean genotypes differed considerably in their responses to soil mulching and irrigation intervals. The Turkish genotype showed the best overall performance for several important yield-related traits, particularly number of pods, 100-seed weight, plant yield, and seed protein content, indicating its good adaptability and productive potential under the conditions of the experiment. Soil mulching generally improved the performance of the crop compared with the non-mulched treatment, demonstrating its beneficial role in maintaining more favorable soil conditions and supporting yield formation. The 7-day irrigation interval also provided better conditions for most of the studied traits than the 14-day interval, emphasizing the importance of maintaining an adequate water supply during crop growth.

The significant interaction among genotype, mulching, and irrigation interval indicates that the performance of fava bean was influenced by the combined effects of these factors. Therefore, selecting a suitable genotype together with an appropriate mulching practice and irrigation schedule is important for achieving higher productivity under water-limited conditions. Based on the results obtained in this study, the Turkish genotype grown with soil mulching and irrigated at 7-day intervals represents a promising combination for improving fava bean productivity under the environmental conditions of central Iraq.

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