Effect of combinations of mineral and nano-fertilizers on the growth and forage yield of three genotypes of barley (*Hordeum vulgare* L.)

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Abstract

A field experiment was conducted in Basrah Governorate at the Agricultural Research Station of the College of Agriculture, University of Basrah, during the winter agricultural season of 2025–2026. The objective was to investigate the effect of combinations of mineral and nano-fertilizers, as well as genotypes, on the growth and forage yield of barley (*Hordeum vulgare* L.). A factorial experiment was laid out using a Randomized Complete Block Design (R.C.B.D) with three replications. The experiment involved two factors: the first factor consisted of three barley genotypes—Syrian, Iranian, and Northern Black, designated as V_1, V_2, and V_3, respectively. The second factor comprised three combinations of nano-fertilizer and mineral nitrogen fertilizer: T_1 (0 g L^{-1} nano-fertilizer with 0 kg N ha^{-1}), T_2 (4 g L^{-1} with 60 kg N ha^{-1}), and T_3 (4 g L^{-1} with 120 kg N ha^{-1}).

The results showed that increasing the fertilizer combinations led to a significant increase in the studied traits. The T_3 combination achieved the highest averages in plant height, number of tillers, forage yield, and harvest index (88.67 cm, 402 tillers m^{-2}, 10089 kg ha^{-1}, and 28.68%, respectively). Meanwhile, the V_3 genotype gave the highest averages in plant height, number of tillers, forage yield, biological yield, and harvest index (88.44 cm, 417.4 tillers m^{-2}, 10236 kg ha^{-1}, 12510 kg ha^{-1}, and 30.64%, respectively). Furthermore, the interaction between the fertilizer combinations and genotypes had a significant effect on plant height, forage yield, and biological yield.

Keywords: Fertilizer combinations, Genotypes, Forage yield.

Introduction

Barley (*Hordeum vulgare* L.) is considered one of the important cereal crops possessing a high capacity to adapt to various environmental conditions. It serves as a vital source of both green and dry forage, particularly in regions suffering from limited water resources and high temperatures. The significance of forage barley is further enhanced by its utility across various vegetative growth stages, as it can provide a substantial amount of green and dry matter while maintaining its nutritional value. This makes it an essential crop in supporting forage production and reducing the feed gap.

Nitrogen fertilization represents one of the most critical agricultural factors influencing barley growth and forage yield, owing to the essential role of nitrogen in synthesizing amino acids, proteins, and enzymes, which directly reflects on leaf formation, increased vegetative area, and dry matter accumulation. Field studies on barley have shown that increasing nitrogen levels can improve growth traits as well as green and dry forage yields; however, the response varies depending on genotypes, environmental conditions, and application rates. [15] found that nitrogen fertilization has a positive effect on green and dry forage yields and certain growth traits in barley cultivars, with clear differences among genotypes in their response to nitrogen levels.

On the other hand, developments in plant nutrition technologies have led to an increased focus on nano-fertilizers, which are characterized by their ultrafine particle size and high specific surface area. This may contribute to improving the efficiency of nutrient delivery, absorption, and utilization by plants when applied at appropriate concentrations. Studies have indicated that the application of nano-fertilizers via foliar spraying can improve certain growth traits and yield components in barley, and the response may vary according to the genotype and the concentration used [17].

Furthermore, studying the integration between traditional mineral fertilizers and nano-fertilizers has become a modern trend in crop nutrition management. Mineral fertilizers can supply the basic nutrient requirements of the plant in the root zone, whereas foliar spraying with nano-fertilizers can enhance plant nutrition during active growth stages [19,12]. Barley genotypes vary in their ability to utilize nutrients, making the selection of a genotype suitable for the fertilization level an important factor in improving forage production. Studies have indicated the presence of genetic variations in green and dry forage yield traits, also showing that certain genotypes were more stable in forage production under different levels of nitrogen fertilization [16]. Results of recent studies also suggest that the interaction between genotypes and plant nutrition systems has become a crucial focus in improving nutrient use efficiency, as not all genotypes respond equally to nutrient levels. Therefore, this study was conducted.

Materials and Methods

A field experiment was conducted at the Agricultural Research Station of the College of Agriculture, University of Basrah, during the winter agricultural season of 2025–2026, to investigate the effect of combinations of mineral and nano-fertilizers on the growth and forage yield of three barley (*Hordeum vulgare* L.) genotypes. The experiment was carried out in a soil with a clay loam texture. The land was prepared, and necessary agricultural operations were performed prior to sowing.

A Randomized Complete Block Design (RCBD) was used in a factorial arrangement to study the effects of two factors—genotypes and fertilizer combinations—as well as their interaction. The first factor consisted of three barley genotypes: Syrian, Iranian, and Northern Black, designated as V_1, V_2, and V_3, respectively. The second factor comprised three combinations of nano-fertilizer and mineral nitrogen fertilizer: T_1(0 g L^{-1} nano-fertilizer with 0 kg N ha^{-1}), T_2 (4 g L^{-1} with 60 kg N ha^{-1}), and T_3 (4 g L^{-1} with 120 kg N ha^{-1}).

The experiment was set up with three replications, resulting in a total of 27 experimental units. The experimental land was plowed, leveled, and divided into blocks and experimental units according to the experimental layout. Irrigation and crop management practices were uniformly applied to all experimental units. Phosphorus fertilizer was also applied at a rate of 100 kg P_2O_5 ha^{-1} in the form of triple superphosphate (20% P), as a single dose before sowing [4]. **S**owing was carried out on November 1, 2025, using a seeding rate 180 kg.ha^{-1} [21].

Data were analyzed statistically using the Analysis of Variance (ANOVA) method for each studied trait, and treatment means were compared using the Least Significant Difference (L.S.D.) test at a probability level of 0.05, as

outlined by [7]. The following traits were measured:

1. Plant Height (cm):

Measured from the soil surface to the tip of the spike for ten randomly selected plants from each experimental unit, and the average plant height per experimental unit was calculated.

2. Number of Tillers (tillers m⁻²):

Calculated by harvesting an area of $0.5\ m^2$ randomly from each experimental unit and then converting the count to a square meter basis.

3. Spike Efficiency (%):

Calculated from the harvested area of $0.5\ m^2$ according to the following formula:

$$\text{Spike Efficiency (\%)} = \left(\frac{\text{Number of spikes m}^{-2}}{\text{Number of tillers m}^{-2}}\right) \times 100$$

4. Green Forage Yield (kg ha⁻¹):

Calculated by harvesting an area of $0.5\ m^2$ randomly from each experimental unit, ensuring harvesting began after the dew evaporated from the plant leaves. The forage yield was weighed in the field using an electronic balance to prevent moisture loss, and the weight was subsequently converted to a kilogram per hectare basis (kg ha^{-1}).

5. Biological Yield (kg ha⁻¹):

Calculated from the total weight of the harvested plants from $0.5\ m^2$ for each experimental unit after air-drying all parts, representing the total dry matter weight (grains + straw). The weight was then converted to a kilogram per hectare basis (kg ha^{-1}).

6. Harvest Index (%):

Calculated based on the following formula, as cited by [9] :

$$\text{Harvest Index (\%)} = \left(\frac{\text{Grain Yield}}{\text{Biological Yield}}\right) \times 100$$

Results and Discussion

1. Plant Height (cm)

Figure (1) shows a significant effect of the fertilizer combinations, where the T_3 treatment recorded the highest plant height of 88.67 cm, with an increase of 21.8% compared to T_1, which gave the lowest average of 72.78 cm. This can be attributed to the vital role of nitrogen in promoting vegetative growth, as it is a fundamental component of amino acids, proteins, chlorophyll, and various compounds essential for cell division and elongation. This result is in agreement with [20]. Additionally, foliar application of nano-fertilizers may have played a role in enhancing this response, particularly because they contain NPK elements; recent reviews indicate that nano-fertilizers can improve nutrient uptake efficiency, which aligns with the findings of [8] .

Furthermore, Figure (1) illustrates the superiority of the V_3 genotype in achieving the highest plant height of 88.44 cm, compared to V_2, which recorded the lowest plant height average of 72.11 cm, with highly significant differences. This indicates that V_3 possesses a high genetic capacity for growth and elongation, and may exhibit greater efficiency in absorbing available nutrients. Moreover, variations in plant height may be associated with genetic differences in internode length.

The interaction between genotypes and fertilizer combinations showed significant differences. The V_3 genotype recorded the highest average plant height at the T_3 level, reaching 98.33 cm. This is likely due to the increased availability of

nitrogen and accompanying nutrients, which enhances the synthesis of proteins and nucleic acids, alongside promoting cell division and elongation, ultimately resulting in increased vegetative growth and plant height. Furthermore, combining nano-fertilizers with mineral fertilizers enhances nutrient absorption, and V_3 appears to have a superior capability in converting absorbed nutrients into vegetative growth. This explanation is consistent with the findings of [15] , who demonstrated the variation among barley genotypes in their response to fertilizer combinations.

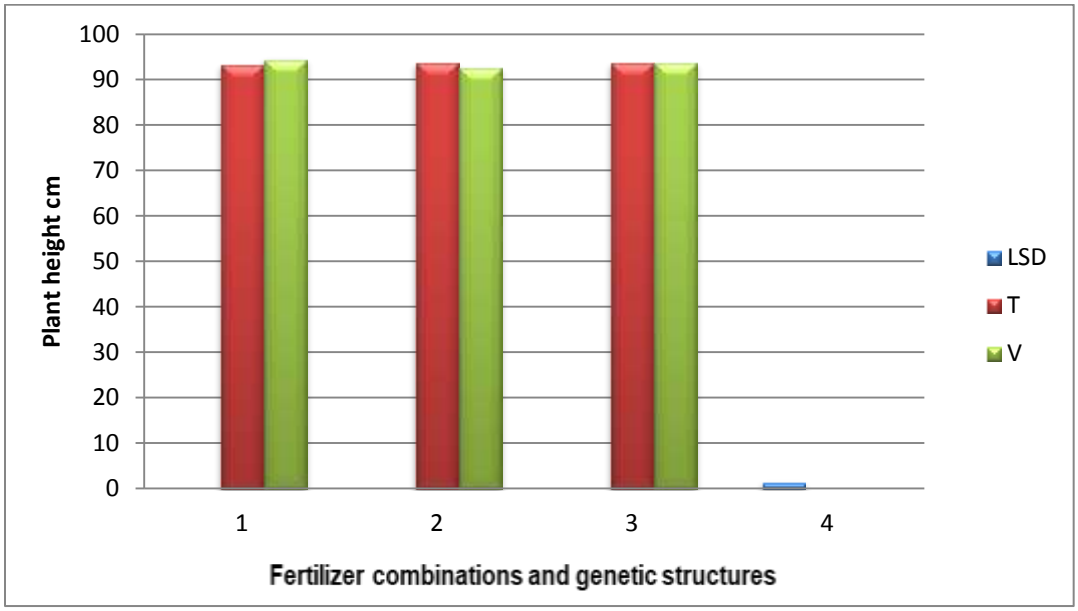


Figure (1): Shows the effect of fertilizer combinations and genotypes on plant height (cm).

2. Number of Tillers (tillers m⁻²)

It can be observed from Figure (2) that the number of tillers increased from 374.4 in T_1 to 402.0 in T_3, indicating significant differences among treatments. The number of tillers is considered one of the important traits in barley, as an increase in tiller formation during early growth stages enhances the probability of producing a greater number of effective spikes, thereby increasing dry matter and final yield, provided that adequate nutritional and environmental conditions are met. The increase in nitrogen in T_3 led to enhanced vegetative growth and tiller formation, given that nitrogen is closely associated with early growth and the development of the vegetative system in cereal crops. This agrees with [11] , who stated that increasing nitrogen levels increased the number of tillers and certain growth components in barley. Additionally, the role of nano-fertilizers may be complementary to mineral fertilization by improving the efficiency of nutrient delivery to the plant and reducing certain forms of loss.

Furthermore, the results in Figure (2) indicate that the V_3 genotype recorded the highest number of tillers at 417.4 tillers m^{-2}, whereas V_2 recorded the lowest average of 356.8 tillers m^{-2}. This increase in the number of tillers is of paramount importance in barley crops utilized for forage production, as the

genotype's capability to form a greater number of tillers can contribute to increasing the vegetative area and dry matter accumulation. It is observed that increasing the fertilizer combinations led to an increase in the number of tillers; however, the interaction was statistically non-significant, as shown in Table (1).

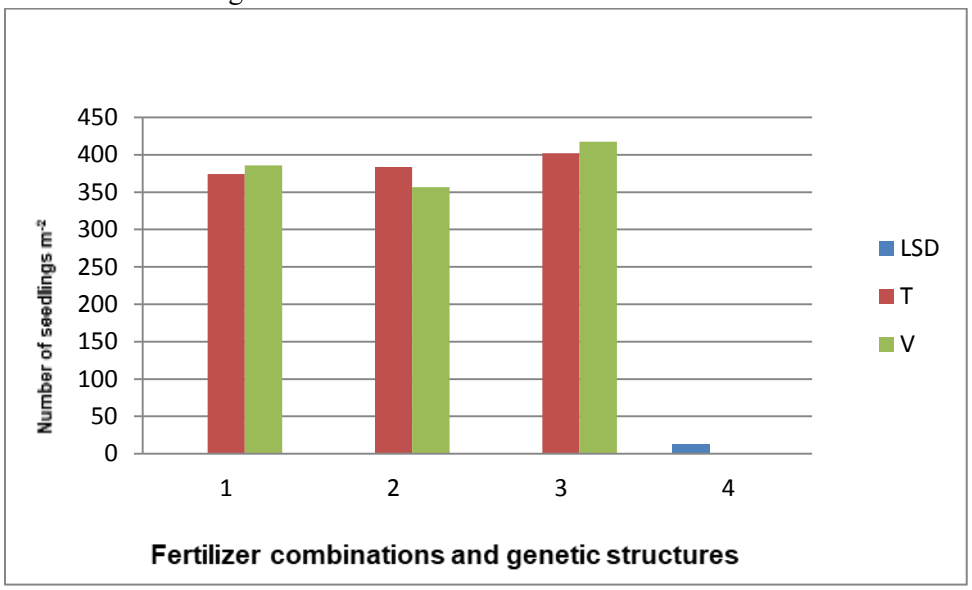


Figure (2): Shows the effect of fertilizer combinations and genotypes on the number of tillers (tillers m^{-2}).

3. Spike Efficiency (%)

Figure (3) shows that there were no significant differences among the fertilizer combinations or the genotypes. This result is of considerable importance, as it indicates that while the increase in fertilization levels led to an increase in the number of tillers, this increase did not significantly affect the percentage of tillers that converted into spikes. This means that the genotypes possessed a comparable level of efficiency in converting tillers into spikes, and this minor apparent difference among values is not sufficient to reach statistical significance. [18], noted that spike efficiency and the number of tillers are influenced by genotypes and fertilizer combinations, but non-significantly. Similarly, the two-way interaction was non-significant, as shown in Table (1)

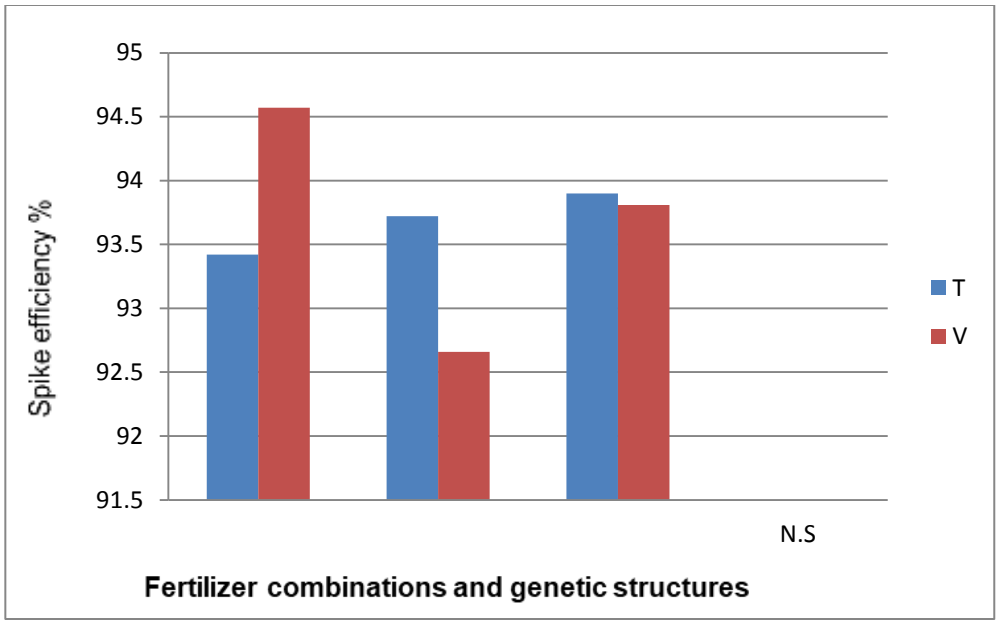


Figure (3): Shows the effect of fertilizer combinations and genotypes on spike efficiency (%).

4. Forage Yield (kg ha^{-1})

Figure (4) showed a significant response of the forage yield to the fertilizer combinations, where the T_3 treatment recorded the highest average of 10089 kg ha^{-1}, with an increase in T_3 compared to T_1 of about 9.3%. This trend reflects the positive effect of growth traits, particularly plant height and the number of tillers. The increase in the number of tillers leads to an increase in vegetative growth and, consequently, an increase in the accumulation of dry matter that contributes to the formation of forage yield. Meanwhile, foliar spraying with nano-fertilizers increases nutrient absorption at higher levels; this interpretation aligns with what [8] stated regarding the potential of foliar nano-fertilization in improving nutrient use efficiency and increasing crop productivity.

Furthermore, Figure (4) illustrates the superiority of the V_3 genotype by recording the highest average forage yield of 10236 kg ha^{-1}, compared to V_2, which recorded the lowest forage yield average of 9231 kg ha^{-1}. This can be attributed to the superiority of V_3 in growth traits, as it recorded the highest plant height and number of tillers, thereby increasing vegetative growth and the green area for dry matter formation, which is reflected in an increased forage yield. This also agrees with the recent study conducted by [6].

The interaction between genotypes and fertilizer combinations showed a significant effect, as shown in Table (1). The $V_3 \times T_3$ combination recorded the highest forage yield of 10510 kg ha^{-1}, whereas the $V_2 \times T_1$ combination recorded the lowest yield of 8530 kg ha^{-1}. This result is directly consistent with [14], who found that increasing foliar fertilization in barley led to a significant increase in green forage yield.

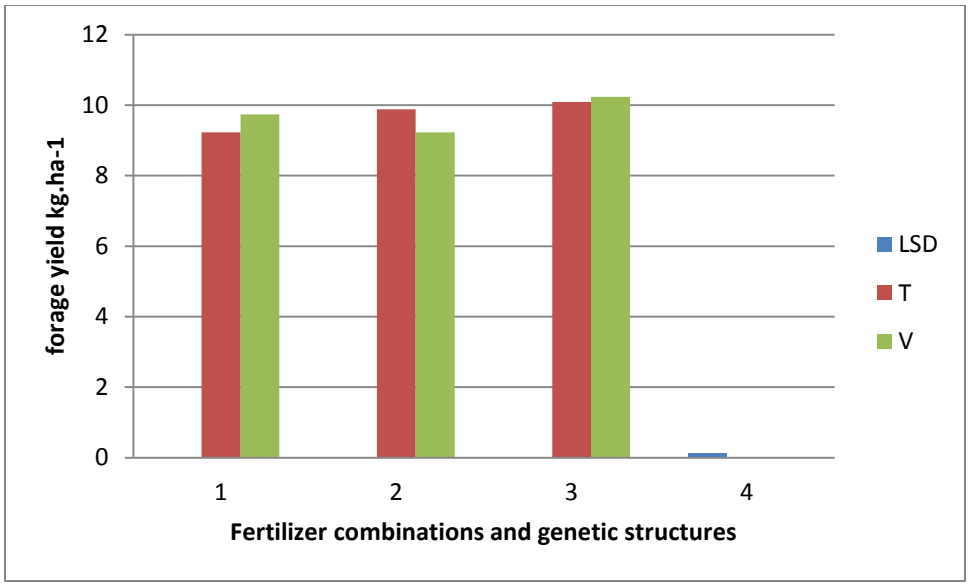


Figure (4): Shows the effect of fertilizer combinations and genotypes on forage yield (kg ha^{-1}).

5. Biological Yield

Figure (5) shows a significant effect of the fertilizer combinations, where the T_2 treatment recorded the highest average biological yield of 12900 kg ha^{-1}, which did not differ significantly from T_3, while T_1 gave the lowest average of 10900 kg ha^{-1}. This is attributed to the fact that the increase in biological yield was not pronounced among the combinations, despite the increase in certain growth traits. These results are in agreement with the findings of [3,2], who reported that nutrient availability enhances vegetative growth and extends its duration, thereby leading to an increase in biological yield.

Furthermore, Figure (5) illustrates the superiority of the V_3 genotype, which recorded the highest average of 12510 kg ha^{-1}, showing a significant increase of 3.90% over V_1. The reason for this variation among genotypes is due to genetic differences in the expression of vegetative traits, particularly the increase in the number of tillers and a high response to nutrient absorption. This aligns with what [5] demonstrated in their study regarding genetic differences in photosynthetic efficiency and nutrient utilization in dry matter accumulation.

The biological yield showed a significant interaction between genotypes and fertilizer combinations, as shown in Table (1). The $V_2 \times T_2$ combination recorded the highest value of 13430 kg ha^{-1}, whereas the $V_2 \times T_1$ combination recorded the lowest value of 10170 kg ha^{-1}. This result is consistent with [10], who found a significant interaction between cultivars and fertilizer levels on biological yield.

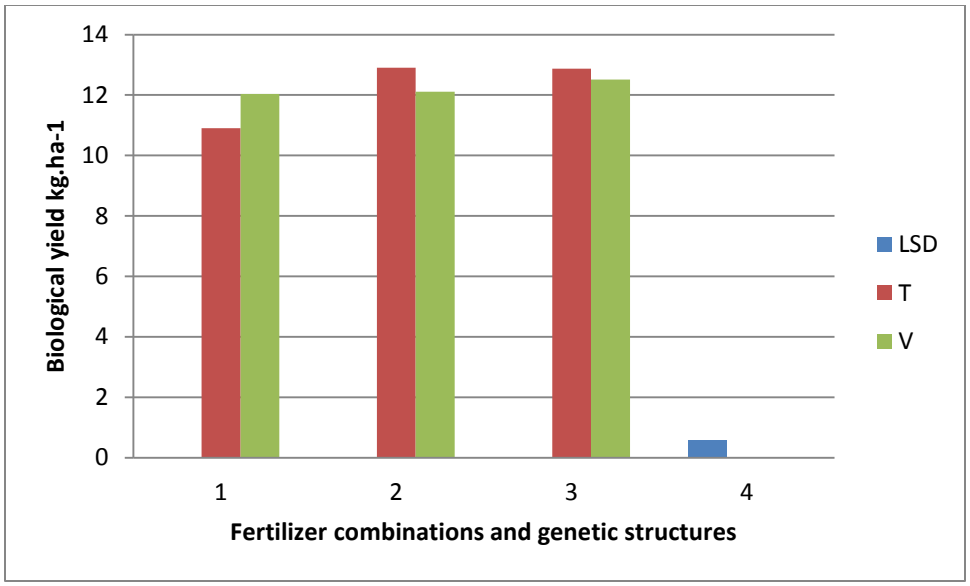


Figure (5): Shows the effect of fertilizer combinations and genotypes on biological yield (kg ha^{-1}).

6. Harvest Index (%)

The results of Figure (6) indicate a significant effect of the fertilizer combinations on the harvest index, where the T_3 treatment achieved the highest harvest index value of 28.68%, while T_1 recorded the lowest value of 25.80%. The increase in the harvest index under T_3 is attributed to the regulation of the translocation of accumulated assimilates to the sink during the grain-filling stage, which increased the ratio of economic yield relative to the total biological yield. This result is in agreement with [22], who noted that high fertilizer levels improve the activity of starch-synthesizing enzymes in grains.

Regarding the genotypes, Figure (6) shows that the V_3 genotype recorded the highest harvest index value of 30.64%, compared to the V_2 genotype, which recorded the lowest average of 23.21%. The superiority of the V_3 genotype is attributed to its genetic capacity to convert photosynthetic products and distribute them with high efficiency toward reproductive parts (i.e., from source to sink). This is supported by [13,1], who stated that differences in the harvest index among genotypes are mainly due to genetic variation in the physiological response during the grain-filling stage and the translocation rate of stored carbohydrate.

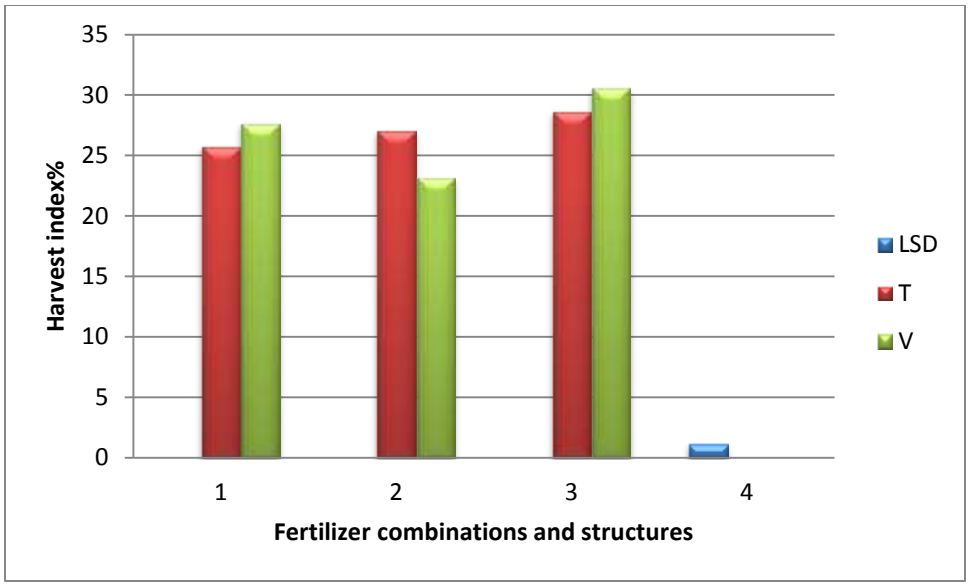


Figure (6): Shows the effect of fertilizer combinations and genotypes on harvest index (%).

Table (1): The effect of the interaction between genotypes and fertilizer combinations on the studied traits.

Genotypes	Fertilization levels	Plant height	Number of tillers	Spike efficiency (%)	Forage yield	Biological yield	Harvest Index (%)
V1	T1	71.33	374.7	93.74	9.330	10.76	27.24
	T2	75.67	375.3	96.28	9.807	12.49	27.28
	T3	87.67	407.7	93.69	10.060	12.87	28.53
V2	T1	67.00	343.7	92.03	8.530	10.17	20.93
	T2	69.33	352.7	91.13	9.467	13.43	22.82
	T3	80.00	374.0	94.81	9.697	12.73	25.89
V3	T1	80.00	405.0	94.49	9.833	11.77	29.24
	T2	87.00	423.0	93.75	10.363	12.77	31.05
	T3	98.33	424.3	93.18	10.510	13.00	31.62
$L.S.D_{0.05}$		2.520	N S	N S	0.2326	0.994	N S

Conclusions

We conclude that the efficiency of the T_3 fertilizer combination ($4\ g\ L^{-1}$ nano-fertilizer with $120\ kg\ N\ ha^{-1}$) led to a significant superiority in most growth and yield traits. Furthermore, the V_3 genotype (Northern Black barley) exhibited superiority by achieving higher response and productivity compared to the Syrian and Iranian cultivars.

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