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Effect of Planting Dates and NPK Fertilization Levels on the Contribution of the Main Stem and Tillers to the Growth and Yield of Sorghum (*Sorghum bicolor* L. Moench)

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Abstract

A field experiment was carried out during the 2024 summer season at the Second Agricultural Research and Experiment Station, College of Agriculture, Al-Muthanna University, Iraq, to assess the impact of three planting dates (14 June, 14 July, and 13 August) and four NPK fertilization levels (F1: 100N–100P–50K kg ha^{-1}, F2: 125N–125P–75K kg ha^{-1}, F3: 150N–150P–100K kg ha^{-1}, and F4: 175N–175P–125K kg ha^{-1}) on tiller production, the contribution of the main stem and tillers to grain yield, harvest index, and total yield revenue of sorghum (*Sorghum bicolor* L. Moench). The experiment followed a split-plot design with three replications.

Planting dates: The highest number of tillers (4.75 tillers $plant^{-1}$) was obtained with early planting on 14 June, while the lowest (2.66 tillers $plant^{-1}$) occurred with late planting on 13 August. The main stem contribution to grain yield peaked at 34.40% in the 13 August planting, whereas the most balanced distribution between stem and tillers was achieved on 14 July. In terms of harvest index, 14 July recorded the highest value (37.40%) and 14 June the lowest (33.11%). The greatest total yield revenue (30,540 thousand IQD ha^{-1}) was recorded for 14 July, while 13 August yielded the lowest (27,387 thousand IQD ha^{-1}).

Fertilization levels: The highest tiller number (4.12 tillers $plant^{-1}$) was produced with F4, while the lowest (3.16 tillers $plant^{-1}$) was with F1. The harvest index reached its maximum with F3 (38.67%) and its minimum with F1 (28.98%). Total yield revenue was highest with F4 (34,029 thousand IQD ha^{-1}) and lowest with F1 (23,103 thousand IQD ha^{-1}).

These findings indicate that planting on 14 July with F4 fertilization offers the optimal balance between vegetative growth and grain yield, thereby maximizing economic returns under the environmental conditions of Al-Muthanna Province.

Keywords: *Sorghum bicolor*, planting date, NPK fertilization, tiller contribution, harvest index, yield revenue.

Introduction

In recent years, the world has witnessed increasing impacts of climate change, including extreme temperature fluctuations and prolonged drought periods, which have led to a decline in the productivity of many staple crops. This challenge necessitates a shift toward cultivating crops capable of adapting to such conditions. Among these crops is sorghum (*Sorghum bicolor* L. Moench), recognized for its high tolerance to drought, elevated temperatures, and soil salinity. Owing to these characteristics, it has been nicknamed the “camel crop,” making it one of the suitable options to address the challenges posed by changing climatic conditions [1].

Sorghum is a dual-purpose cereal crop, ranking fifth in global importance and grain production after wheat, rice, maize, and barley. It is distinguished by its high nutritional value, containing 2–5% fat, 70–80% carbohydrates, and 11–13% protein. Its protein serves as an alternative food source for individuals suffering from diabetes and digestive disorders, as it is gluten-free. Furthermore, sorghum grains are a source of vitamin B [2]. The significance of this crop is further increasing due to its expanding use in both human and animal nutrition. Its grains are used in bread production, poultry feed, and as a component (up to 50%) of cattle fattening rations. Additionally, its stems and vegetative biomass are utilized as green fodder, in hay and silage production, and for biofuel manufacturing [3,4].

Planting date is considered one of the most critical factors influencing the growth and development stages of sorghum plants. The timing of planting determines the photoperiod and temperature regimes to which the plants are exposed, thereby affecting the number of tillers produced and the extent of their contribution to yield formation. Early planting ensures a longer vegetative growth period and more favorable temperatures, which promote the development of early tillers with higher potential to contribute to yield. In contrast, late planting shortens the vegetative growth period, reduces the ability of tillers to bear grains, and consequently diminishes their contribution to total production [5].

Balanced fertilization with NPK is a fundamental field practice for enhancing growth efficiency and maintaining nutrient supply balance throughout the different growth stages. Nitrogen plays a key role in promoting vegetative growth and tiller production, while phosphorus supports root development, accelerates flowering, and enhances grain formation. Potassium is essential for improving photosynthetic efficiency and facilitating carbohydrate translocation to the grains.

Several studies have reported that balanced fertilization enhances the contribution of both the main stem and tillers, especially when nutrient availability coincides with the critical stages of grain formation[6,7].

Studying the contribution of the main stem and tillers to grain number and total yield provides deeper insight into the distribution of productivity among different plant components. It also aids in identifying the optimal combinations of planting dates and fertilization levels that achieve a balance between vegetative and reproductive growth, thereby improving the economic return for farmers. Accordingly, this study aims to evaluate the effect of three planting dates and four NPK fertilization levels on the contribution of the main stem and tillers to growth traits and yield of sorghum in Al-Muthanna Province, using a randomized complete block design in a split-plot arrangement.

Materials and Methods

The field was conducted during the summer growing season of 2024 at the Second Agricultural Research and Experiment Station, the College of Agriculture, University of Al-Muthanna, located in the Al-Bandar area (31.19° N latitude, 45.18° E longitude). The primary objective of the study was to assess the impact of different planting dates and NPK fertilization levels on the growth performance and yield of the sorghum cultivar *Giza*. Before planting, random soil samples were collected from multiple points across the experimental site at a depth of 0–30 cm. These samples were thoroughly mixed to form a composite sample, which was then analyzed for its physical and chemical properties (Table 1). Land preparation involved two perpendicular plowings, followed by leveling and division of the area into 36 experimental plots, each measuring 3.0 × 3.5 m^2.

The experimental layout followed a split-plot arrangement within a Randomized Complete Block Design (RCBD) with three replications. NPK fertilizer treatments:

- **F1:** 100 kg N, 100 kg P, 50 kg K ha^{-1}
- **F2:** 125 kg N, 125 kg P, 75 kg K ha^{-1}
- **F3:** 150 kg N, 150 kg P, 100 kg K ha^{-1}
- **F4:** 175 kg N, 175 kg P, 125 kg K ha^{-1}

The subplots were allocated to three planting dates:

- **D1:** 14^{th} June
- **D2:** 14^{th} July
- **D3:** 13^{th} August

Each replication contained 12 experimental units, giving a total of 36 plots. Each plot comprised four ridges, spaced 75 cm apart. Sowing was carried out manually on the designated dates, placing three seeds per hill at 20 cm intervals along the upper third of the ridge. Seedlings were thinned to one plant per hill two weeks after emergence. Prior to planting, a uniform irrigation was applied to ensure even germination.

Phosphorus fertilizer, in the form of triple superphosphate (46% P_2O_5), was applied in a single pre-sowing dose and incorporated into the soil. Nitrogen, supplied as urea (46% N), was split into two equal applications: the first at 20 days after emergence and the second at the booting stage. Potassium was provided as potassium sulfate (42% K_2O) in two splits: the first at 30 days after sowing and the second at 50% flowering[8].

To control stem borer infestation, Diazinon 10% granules were applied at 6 kg ha^{-1} directly into the plant whorl at the 4-leaf stage, followed by a second application 15 days later[9]. Irrigation was scheduled according to crop requirements, and manual weeding was performed whenever necessary. To minimize bird damage, sorghum panicles were covered at flowering, and harvesting was carried out at physiological maturity for each planting date.

Measured Traits

Five vegetative growth parameters were recorded:

1. Number of tillers (tillers $plant^{-1}$)
2. Contribution of the Main Stem and Tillers to the number of grains (%)
3. Contribution of the Main Stem and Tillers to Grain Yield (%)
4. Harvest Index (%)
5. Total Yield Revenue (thousand IQD ha^{-1})

Table 1. Physical and chemical characteristics of the soil before planting

Soil properties		Value	Unit
pH		7.52	
E.C (1:1)		5.72	dc m^{-1}
Available Nitrogen		21.90	mg kg^{-1} soil
Available Potassium		100.6	
Available Phosphorus		16.21	
Soil separators	Clay	9.7	%
	Silt	29.6	%
	Sand	60.7	%
Soil Texture		Sandy loam	

All laboratory analyses were performed at the Fadak Central Laboratory for Analyses, affiliated with the Holy Alawi Shrine in Al-Najaf Al-Ashraf, Iraq

Results and Discussion

Number of tillers (tillers $plant^{-1}$)

The results presented in Table (2) indicate a significant effect of planting dates on the number of tillers per plant. The earliest planting date (14 June) recorded the highest mean value of 4.75 tillers $plant^{-1}$, followed by the second date (14 July) with 3.71 tillers $plant^{-1}$, while the latest planting date (13 August) produced the lowest mean of 2.66 tillers $plant^{-1}$. This trend can be explained by the fact that early planting dates, combined with higher temperatures and longer photoperiods, provide favorable conditions for plant tillering. Under such conditions, plants benefit from a prolonged vegetative growth period, which promotes the formation of a greater number of tillers. In contrast, the third planting date is characterized by a shorter vegetative phase and a gradual decline in temperature, which limits the plant's capacity for tiller production. Consequently, plants tend to accelerate their growth and shift to flowering at the expense of vegetative development. These findings are consistent with [10], who reported that elevated temperatures under adequate light conditions enhance tiller formation in Poaceae species.

Table (2) also reveals an increase in the number of tillers with higher NPK fertilization levels. The highest mean (4.12 tillers plant^{-1}) was obtained with the F4 treatment, whereas the lowest mean (3.16 tillers plant^{-1}) was recorded under the F1 treatment. This result may be attributed to the role of nitrogen and phosphorus in stimulating tillering. According to [10], the availability of nutrients, particularly nitrogen, encourages tiller formation in cereal crops. These findings are in agreement with those reported by [11,12].

Regarding the interaction between planting dates and NPK levels, the trend was consistent with the effects of each factor when considered individually. The D1F4 combination produced the highest mean of 5.20 tillers plant^{-1}, whereas the D3F1 combination recorded the lowest mean of 2.30 tillers plant^{-1}. The superiority of the D1F4 combination can be attributed to the same reasons discussed for the individual effects of each factor.

Table (2): Effect of NPK fertilizer levels, planting dates, and their combination on the quantity of tillers (tiller plant^{-1})

Average per NPK Level	Planting Dates			NPK Levels
	D3 (August 13)	D2 (July 14)	D1 (June 14)	
3.16	2.30	3.20	4.00	F1
3.65	2.66	3.50	4.80	F2
3.90	2.70	4.00	5.00	F3
4.12	3.00	4.16	5.20	F4
	2.66	3.71	4.75	Average per Date
Interaction	NPK Levels		Planting Dates	LSD (0.05)
0.1109	0.0675		0.0595	

Contribution of the Main Stem and Tillers to number of grains

Monitoring the contribution of tillers under different planting dates revealed that the main stem consistently accounted for the largest share of grain number, with contributions of 24.03%, 26.51%, and 31.96% for the first, second, and third planting dates, respectively. These were followed by the first, second, and third tillers in descending order of contribution, while the fourth and fifth tillers recorded the lowest percentages of 7.45% and 11.30% for the first and second planting dates, respectively. In the third planting date, the contribution was limited to the third tiller, as plants sown on this date were unable to produce more tillers. This limitation was due to the late planting and the accompanying climatic conditions, which did not favor the production of additional tillers, in addition to the shorter crop growth duration.

As illustrated in Figures (1, 2, and 3), the balance of contribution between the main stem and the tillers was more uniform in the first planting date, followed by the second, compared with the third planting date. In the latter, the main stem and the first tiller dominated the contribution to grain production. This trend is expected and can be attributed to the climatic conditions associated with each planting date. In earlier planting dates, the environment supported the emergence, development, and growth of tillers under favorable conditions, allowing for a more balanced contribution to grain production. Conversely, in the third planting date, the reduction in the suitable climatic window as the plants advanced in age limited tiller formation, and the later-emerging tillers had reduced contributions due to their exposure to less favorable environmental conditions during grain development.

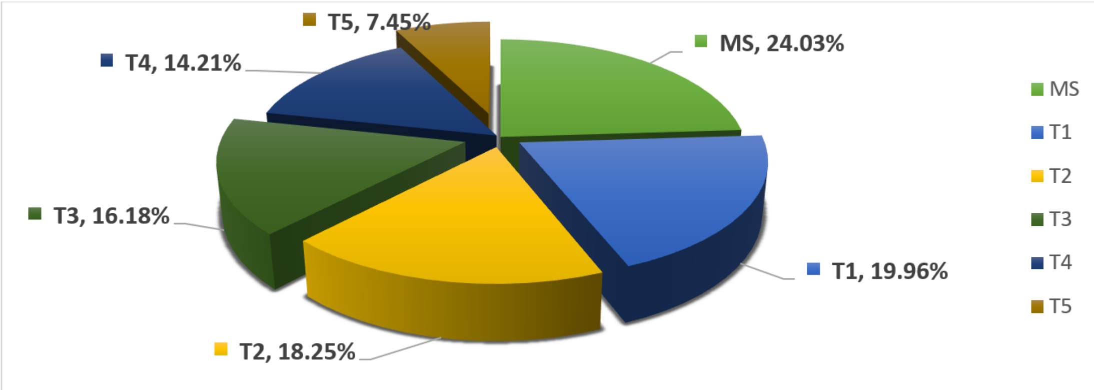


Figure1 : Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the number of grains at the first planting date

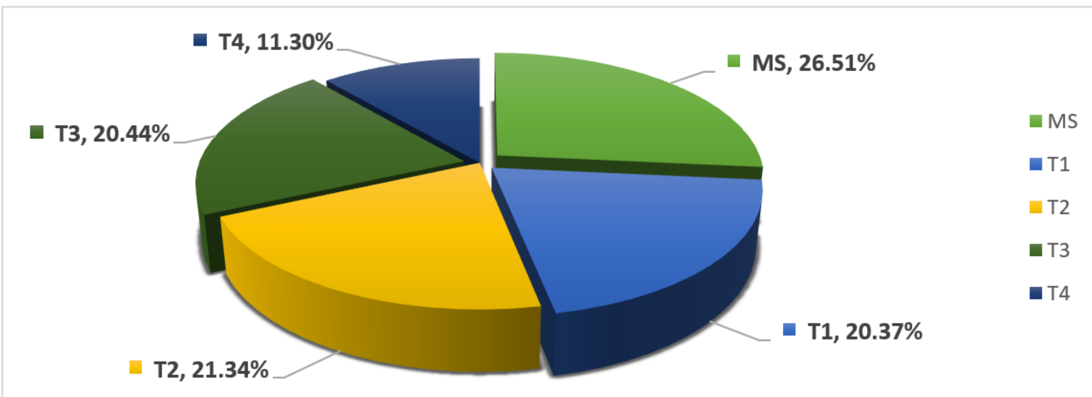
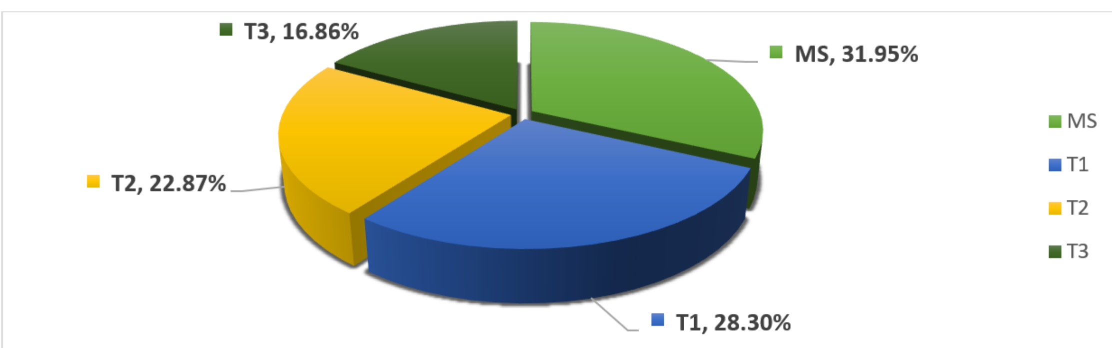


Figure2 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4) to the number of grains at the second planting date



:Contribution of the main stem (MS) and tillers (T1, T2, T3) to the number of grains at the third planting date3 Figure

Analysis of the contributions of the main stem and tillers under different NPK fertilization levels showed that the main stem consistently had the highest contribution to grain number across all four fertilization treatments, whereas the fifth tiller contributed the least. The first, second, and third tillers exhibited relatively balanced contributions, while the fourth tiller showed a marked imbalance. This imbalance is likely attributed to the environmental conditions prevailing during its development, which were not highly favorable for its growth and differentiation, in addition to its limited capacity for dry matter accumulation and distribution due to the short time available before reproductive transition, thereby reducing its contribution. It is important to note that a high contribution from the main stem alone cannot be considered a sufficient indicator of fertilization efficiency. Such dominance may occur at the expense of tillers, particularly the later-emerging ones, potentially limiting the plant's total yield potential. In contrast, a balanced contribution between the main stem and tillers—and among the tillers themselves—is a key indicator of effective fertilization. This balance was most evident in treatments F3 and F4, which can be attributed to the precise synchronization between nutrient availability (especially nitrogen) and the critical growth stages of the tillers, creating optimal conditions for their differentiation and grain set. Variations among other treatments were mainly due to differences in the amounts of fertilizer applied and the accompanying climatic conditions, which often restricted the contribution of tillers, particularly those emerging later, to the final grain yield.

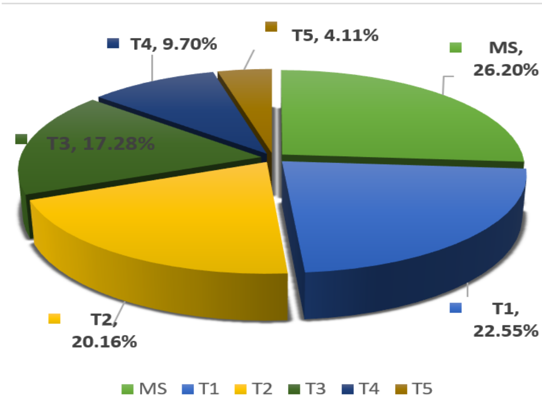


Figure5 : Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the number of grains per plant at the second fertilization level (F2).

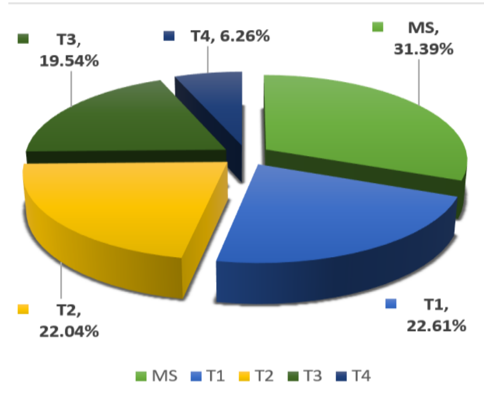


Figure4 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4) to the number of grains per plant at the first fertilization level (F1).

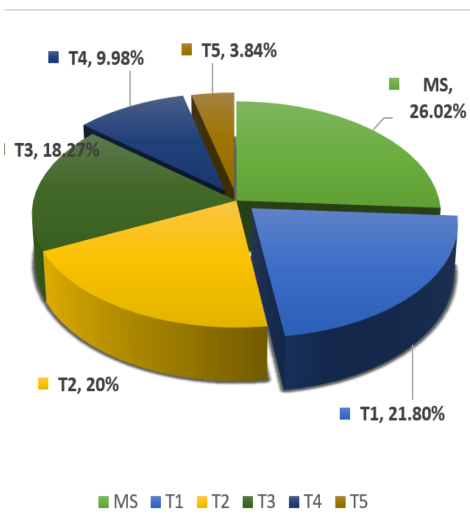


Figure5 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the number of grains at the third fertilization level (F4).

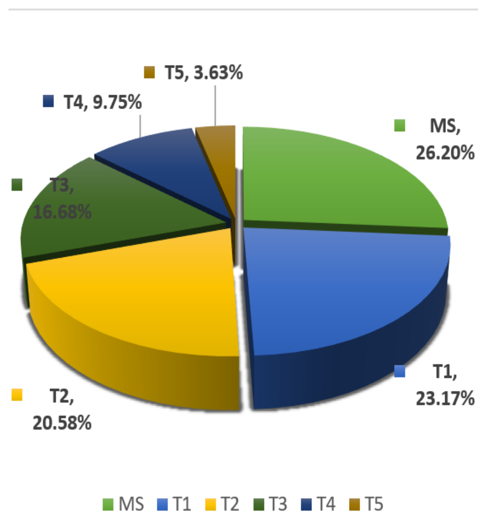


Figure6 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the number of grains at the third fertilization level (F3).

Contribution of the Main Stem and Tillers to Grain Yield (%)

An examination of Figures (8, 9, and 10) depicting the contribution of the main stem and tillers to grain yield under different planting dates revealed that the main stem consistently exhibited the highest contribution, accounting for 25.30%, 27.36%, and 34.40% for the first, second, and third planting dates, respectively. This was followed by the contribution of the first tiller, with subsequent tillers showing progressively lower contributions as their emergence was delayed.

The results further indicated a decline in the number of tillers with later planting dates, reaching 5, 4, and 3 tillers for the first, second, and third planting dates, respectively. The most balanced contribution between the main stem and tillers was observed in the second planting date, reflecting the favorable climatic conditions prevailing during the emergence, growth, and development of tillers in this treatment, compared with the first and third planting dates.

In the first planting date, a sharp decline was recorded in the contribution of the fifth tiller (7.53%), which is expected due to its late emergence, shorter growth duration, and the less favorable environmental conditions during its development. In the third planting date, plants produced only three tillers alongside the main stem, with the main stem maintaining the highest contribution to grain yield. This was likely because the main stem developed under more favorable environmental conditions than the tillers. Nevertheless, the tillers exhibited a relatively balanced contribution regardless of whether the planting date achieved the highest yield. This may be attributed to the relatively close emergence timing of the main stem and tillers, as all were influenced by the shortened vegetative growth period resulting from the late planting date. This factor increased the contribution of the third tiller in particular, which reached 15.98%.

Across all planting dates, the first and second tillers had contributions that were closer to that of the main stem, which can be attributed to their earlier emergence and longer developmental period up to harvest.

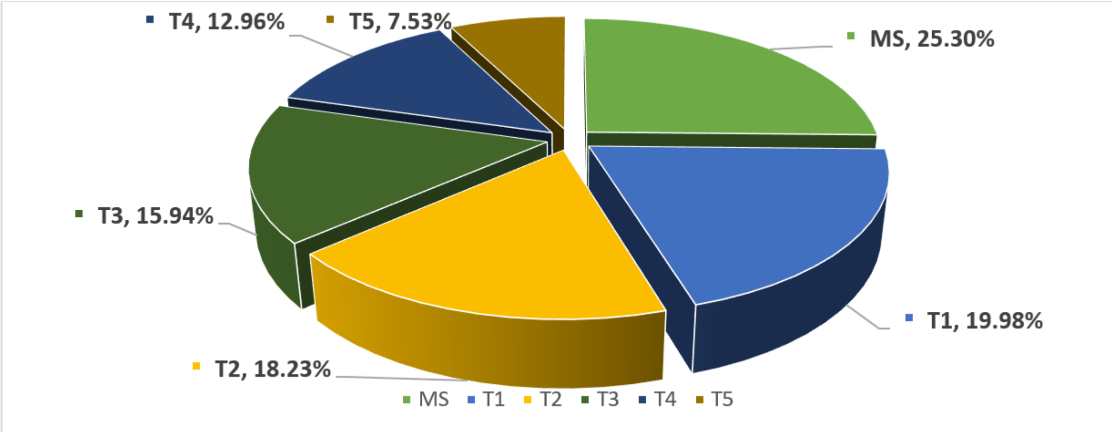


Figure6 :Contribution of the main stem (MS) and the branches (T1, T2, T3, T4, T5) to the grain yield per plant (tons per hectare) at the first planting date.

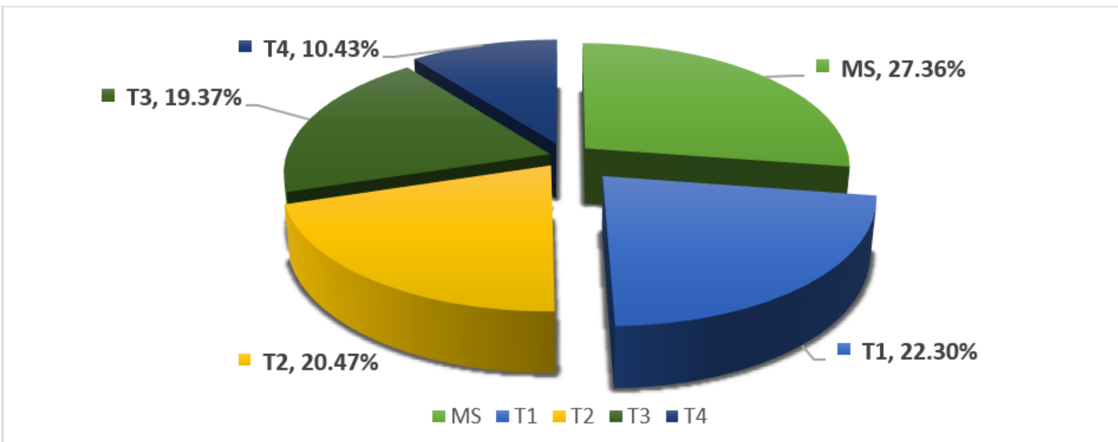


Figure7 :Contribution of the main stem (MS) and the branches (T1, T2, T3, T4) to the grain yield per plant (tons per hectare) at the second planting date.

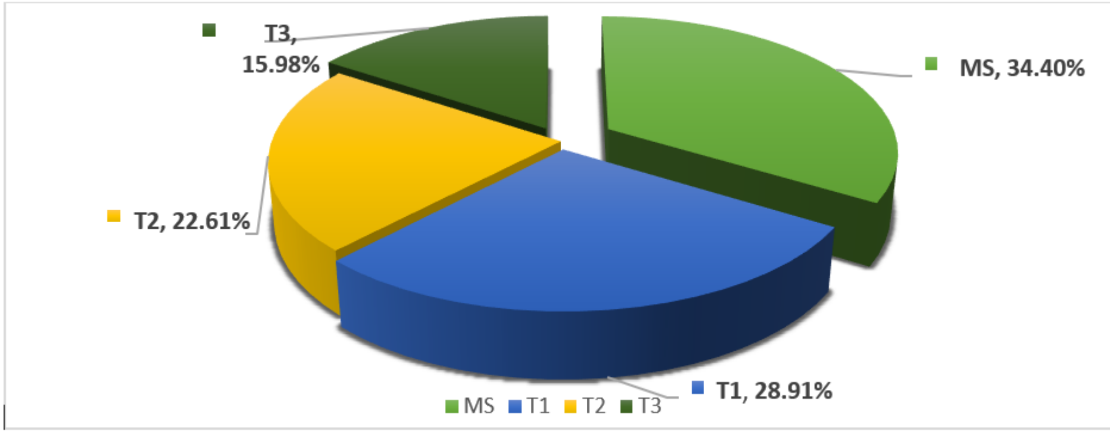


Figure 8: Contribution of the main stem (MS) and the branches (T1, T2, T3) to the grain yield per plant (tons per hectare) at the third planting date.

The contribution results under the influence of fertilization levels indicate an increase in the number of tillers with the increase in the fertilization level (NPK) by one tiller. This, in turn, will increase the grain yield, considering that this tiller is productive and makes a significant contribution, as its contribution reached 3.43%, 3.08%, and 3.22% for the second, third, and fourth fertilization levels, respectively. Notably, this contribution was an addition rather than at the expense of other tillers. This is attributed to the role of fertilizer in enhancing tiller production through the abundance of macronutrients (NPK), which play a major role in the production, growth, and development of tillers.

It was also observed that the main stem’s contribution was consistent across all fertilization levels, with the highest recorded at the first level, due to its precedence in emergence and development under favorable climatic conditions. The same pattern was observed in the first and second tillers, reflecting the role of nutrients in enhancing the growth of these tillers and increasing their contribution to grain yield, where their contribution was close to that of the main stem.

The results also revealed weaker performance of the fourth tiller at the first fertilization level compared to its contribution under other levels. This is due to the lower amount of fertilizer applied at the first level (F1), which had a clear impact on the contribution of the fourth tiller, along with the complete absence of the fifth tiller. This deprived the plants in the first level treatment of an additional contribution that could have boosted the grain yield. The low contribution of late tillers is due to the timing of their emergence, growth, and development, which coincides with environmental stress conditions that shorten their growth period until harvest, as they emerge later compared to the main stem and early tillers.

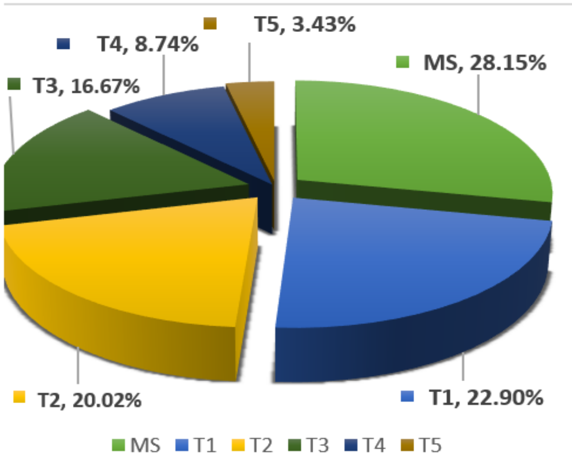


Figure10 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the grain yield per plant (tons ha^{-1}) at the second fertilization level (F2).

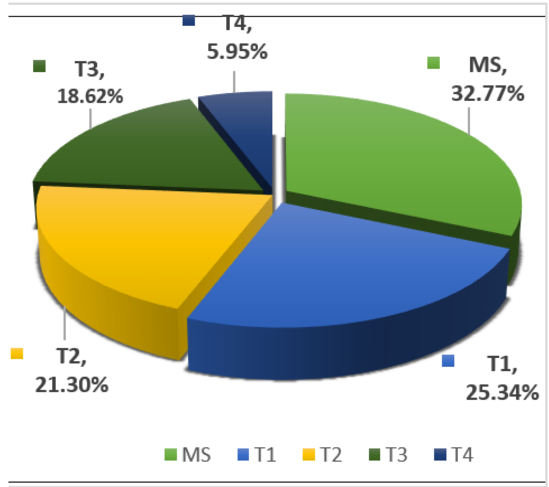


Figure9 :Contribution of the main stem (MS) and tillers (T1, T2, T3, T4) to the grain yield per plant (tons ha^{-1}) at the first fertilization level (F1).

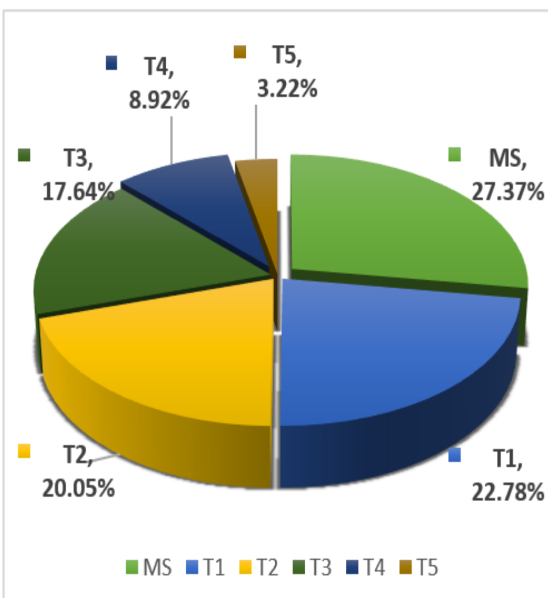


Figure 11:Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the grain yield per plant (tons ha^{-1}) at the fourth fertilization level (F4)

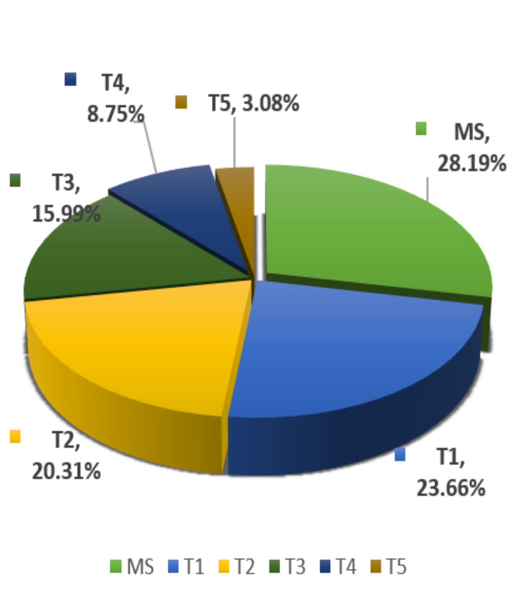


Figure 13: Contribution of the main stem (MS) and tillers (T1, T2, T3, T4, T5) to the grain yield per plant (tons ha^{-1}) at the third fertilization level (F3).

Harvest Index (%)

The results in Table (3) show a significant effect on the harvest index under the influence of planting dates. The second planting date (July 14) significantly outperformed the others with the highest mean value of 37.40%, followed by the third planting date (August 13) with a mean of 35.69%, while the first planting date recorded the lowest mean value of 33.11%, significantly lower than the other two dates. This variation may be explained by the efficiency of converting photosynthetic products (source) into grains (sink). Planting on the second (July 14) and third (August 13) dates likely reduced excessive, non-economic vegetative growth, allowing greater amounts of carbohydrates and proteins to be directed toward grain formation, thereby increasing the harvest index. In contrast, early planting led to excessive vegetative growth, creating a large source but without an effective enough sink, which reduced conversion efficiency and consequently lowered the ratio of grain yield to total biological yield[13].

The results in Table (3) also indicate that the harvest index differed significantly under the influence of NPK fertilization levels. The F4, F3, and F2 levels recorded mean values of 38.35%, 38.67%, and 35.60%, respectively, with no significant differences among them, while the F1 level recorded 28.98%, significantly lower than the other levels. This may be attributed to the fact that higher fertilization levels enhanced the plant's ability to develop floral clusters and produce grains more effectively, which was reflected in the increase in grain yield (Table 17) proportionally to overall growth. Conversely, the lower fertilization level did not provide sufficient quantities of essential nutrients (Tables 2, 3, and 4), negatively affecting grain formation compared to vegetative growth, and consequently reducing the harvest index. These findings are consistent with those reported by [14,15].

As for the interaction effect, the combination (D2F3) recorded the highest mean value of 43.07%, without a significant difference from the combinations (D2F2) and (D3F4), which achieved mean values of 38.46% and 40.24%, respectively. In contrast, the combination (D1F1) exhibited the lowest mean value of 26.49%, without a significant difference from the combination (D2F1), which recorded a mean of 30.86%. This outcome may be attributed to the increase in grain yield in the superior combinations and the relatively lower biological yield compared with the other combinations.

Table (3). Effect of NPK fertilizer amounts, planting dates, and their combination on the harvest index (%)

Average per NPK Level	Planting Dates			NPK Levels
	D3 (August 13)	D2 (July 14)	D1 (June 14)	
28.98	29.60	30.86	26.49	F1
35.60	35.91	38.46	32.43	F2
38.67	37.02	43.07	35.93	F3
38.35	40.24	37.22	37.59	F4
	35.69	37.40	33.11	Average
Interaction	NPK Levels		Planting Dates	LSD (0.05)
4.783	4.527		1.464	

Total Yield Revenue (thousand IQD ha^{-1})

The results presented in Table (4) indicate that total yield revenue was influenced by planting dates and NPK levels. The second planting date (July 14) and the first planting date (June 14) outperformed the third planting date (August 13) in terms of total yield revenue, with mean values of 30,540, 30,465, and 27,387 thousand IQD ha^{-1}, respectively. The superiority of the second planting date in total yield revenue may be attributed to achieving a clear balance between biological yield and grain yield, as this date was characterized by a high number of tillers and total plant dry matter, along with good grain production, which positively reflected on the overall revenue. This balance indicates that, at this planting date, the plant did not solely focus on vegetative growth but was also able to produce a sufficient quantity of grains, explaining the higher economic return (Tables 23 and 24).

The results in Table (4) also show that total yield revenue was affected by fertilization levels, with the F4 level recording the highest mean revenue of 34,029 thousand IQD ha^{-1}, while the F1 level recorded the lowest mean revenue of 23,103 thousand IQD ha^{-1}. This could be due to the superiority of F4 in both total grain yield revenue and total biological yield revenue (Tables 23 and 24).

Table (4). Effect of planting dates, NPK fertilizer levels, and their interaction on total yield revenue (thousand IQD ha^{-1})

	Planting Dates	

NPK Levels	D1 (June 14)	D2 (July 14)	D3 (August 13)	NPK Levels
23103	22629	23931	22749	F1
28296	25881	29739	29271	F2
32415	29319	34320	33609	F3
34029	31719	34170	36198	F4
	27387	30540	30465	Average
	Interaction	Planting Dates	NPK Levels	LSD (0.05)
	611	410	350	

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