The Role of Fertilization in Mitigating the Effects of Water Stress on Vegetative Growth and Yield of Maize (*Zea mays* L.)

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Abstract The study was done in Wasit Governorate, Iraq, with a split-plot arrangement within a randomized complete block design (RCBD) with three replicates. Full irrigation (I1, 100%), moderate stress (I2, 50%), and severe stress (I3, 25%) were considered in the main plots, while in the subplots, five fertilization regimes were considered (control (Fo), full chemical fertilizer (Fl), full organic fertilizer (F2), 40% organic + 60% chemical (F3), and 60% organic + 40% chemical (F4) . Measured growth parameters included days to flowering, leaf area, ear diameter, grains per row, total, and mean grain yield. Water stress was the main factor suppressing growth and yield parameters. The highest grain yield (5.09 Mg ha^{-1}) was recorded from I1 irrigation, while I3 recorded the least (3.73 Mg ha^{-1}). In addition to the impacts of irrigation, fertilization also recorded an impact where F3 was always better than all the treatments, whereby the highest mean grain yield (5.63 Mg ha^{-1}) and ear diameter of (6.04 cm) were recorded, while the control F0 was the lowest across all the parameters. I1 × F3, with the most doses of fertilizer and irrigation, led to the highest yield of grain, at 6.48 Mg ha^{-1}, and I3 × F0 had the lowest yield of grain, at 3.25 Mg ha^{-1}. This shows that if all of the optimal conditions (40% organic and 60% chemical fertilizer, along with full irrigation) are met, maize growth and yield are extremely enhanced, and balanced fertilization strategies can reduce the impact of water drought. Using appropriate fertilization methods can help produce maize sustainably.

Keywords:: Maize, water stress, organic fertilizer, chemical fertilizer, grain yield, Vegetative Growth.

Introduction

Maize (*Zea mays* L.) is one of the most important crops due to its wide use as food, livestock feed, pharmaceutical, and industrial feedstock. In addition, it is also used as a feedstock in biofuel and bioproduct industries [1], but maize productivity is highly constrained to climatic fluctuations [2], especially water stress, which represents the biggest challenge factor for crop productivity in arid and semi-arid regions, especially in Iraq, where large lakes show drought patterns via remote sensing [3, 4]. Recent studies confirm severe water deficits in Iraqi lakes using NDWI indices and statistical analysis of climate-runoff relations in Babylon province, exacerbating crop vulnerabilities [5]. Literature has demonstrated that the lowering of crop productivity with water scarcity is linked to physiological processes, including photosynthesis, stomatal regulation, osmotic adjustment, and reproductive development [6]. Simultaneously, the other challenging factor is the soil fertility, whose progressive decline requires efficient Integrated Nutrient Management (INM) strategies. Organic fertilizers hold some advantages over chemical fertilizers, such as their enhancement of microbial activity and increasing water-holding capacity [7], whereas chemical fertilizers still hold attractive advantages, such as supplying

readily available nutrients that support rapid vegetative and reproductive growth [8]. Several researchers have reported several advantages of combining organic and chemical fertilizers in enhancing nutrient absorption, physiological attributes, and yield performance of maize [9]. However, findings across the literature remain inconsistent regarding several points, particularly the optimal mixing ratios of organic and chemical fertilizers, the efficiency of these ratios under different levels of water scarcity, and their effectiveness in enhancing maize drought resilience.

Unfortunately, limited studies have jointly evaluated multiple levels of water stress alongside various organic–chemical fertilizer combinations. There is also insufficient evidence identifying the optimal fertilizer blending ratio that enhances physiological and agronomic responses under moisture-deficient conditions. Furthermore, literature lacks a comparative and analytical perspective that synthesizes contrasting research outcomes to guide practical nutrient and irrigation management in dry environments.

For these reasons, this work aims to address these gaps by investigating the interactive effects of three irrigation levels and five fertilization treatments involving different organic-to-chemical fertilizer ratios on the vegetative growth and yield performance of maize. This study provides valuable insights into identifying the optimal integrated fertilization strategy to minimize the adverse effects of water scarcity and sustain maize productivity in arid and semi-arid regions.

Material and Methods

2.1 Experiment Site.

The field experiments were conducted in a private field in Wasit Governorate, Iraq, during the fall season of 2024. The work aims to study the impact of mixing organic and mineral fertilizers and water stress levels on improving the growth and productivity of yellow corn.

2.2Soil Preparation and Experimental Units.

The soil was prepared by performing two perpendicular plowings using a rototiller, followed by a disc harrowing and soil leveling process. The plot was then divided according to a randomized complete block design with a split-plot arrangement, with three replicates. The experimental unit area was 9 m², with a distance of 75 cm between rows and 25 cm between plants. Planting was carried out on Aug. 19, 2024, after testing the germination rate of the synthetic variety (515), which reached 93% .

2.3 Fertilizer application and agricultural operations.

Organic fertilizer was added in one batch before planting at a rate of 10 tons/ha. Compound fertilizer (NPK) was also added at a rate of 320 kg/ha according to the manufacturer's recommendations. It was mixed well with the organic fertilizer in the soil before planting. All crop maintenance operations were carried out. The corn stem borer was controlled using the effective granular pesticide Diazinon (10%) once after noticing the infestation, as indicated in the literature [10]. The pesticide granules were placed by feeding into the growing tip of the plant. To ensure complete plant emergence, two irrigations were given before the start of the water stress treatments.

2.4 Experimental treatments .

The experiments were conducted using a split-plot arrangement within a randomized complete block design (RCBD). The main plots were assigned to three levels of water stress: I1 (100% irrigation), I2 (50% irrigation), and I3 (25% irrigation). The subplots consisted of five fertilization treatments, including F0 (unfertilized control), F1 (full recommended dose of chemical fertilizer, NPK), F2 (full recommended dose of organic fertilizer and sheep manure), F3 (40% organic +

60% chemical fertilizer), and F4 (60% organic + 40% chemical fertilizer).

Three irrigation levels were applied, which are I1: Full irrigation (100% crop evapotranspiration, ETc), I2: Moderate water stress (50% ETc), and I3: Severe water stress (25% ETc). Two uniform irrigations were applied before emergence to ensure establishment, then treatments began. In addition, five fertilizer treatments were tested. Full doses were organic fertilizer (sheep manure) = 10 tons ha^{-1}; chemical fertilizer (NPK) = 320 kg ha^{-1}. All fertilizers were mixed into the soil before planting (Aug 19, 2024). Table 1 shows the treatment type with its description and the exact amounts applied. Fertilizers were broadcast and thoroughly mixed with the soil after plowing but before planting the maize synthetic variety (515) .

Table 1. The treatment type, with its description

Exact Amounts Applied	Description	Treatment
0 tons organic + 0 kg NPK	Control (no fertilizer)	F0
0 tons organic + 320 kg NPK ha^{-1}	100% chemical	F1
10 tons sheep manure ha^{-1} + 0 kg NPK	100% organic	F2
4 tons sheep manure ha^{-1} + 192 kg NPK ha^{-1}	40% organic +60% chemical	F3
6 tons sheep manure ha^{-1} + 128 kg NPK ha^{-1}	60% organic +40% chemical	F4

2.5 The Traits Measured.

The following traits were measured: Number of days from planting to 50% female flowering (days): The time period (days) from planting to 50% female flowering was calculated for plants in the experimental unit based on [11]. Leaf area (cm2): Leaf area was measured by multiplying the length of the leaf below the ear by the maximum leaf width (cm) × 0.75, and multiplying by the number of leaves, according to Al-Sahouki et.al. [12]. Ear diameter (cm): Ear diameter was measured for samples randomly taken from the experimental unit, as the average of the five ear diameters, using a Vernier micrometer. Number of grains per row (grain): A random sample of five ear diameters was taken, and the number of grains in each ear was calculated, and the average was taken. Finally, the total grain yield (megagram ha-1): Multiply the yield of one plant (g) by the plant density per hectare (53333) plants ha-1 [13].

2.6 Statistical Analysis.

Statistical analysis was conducted using the General Linear Model (GLM) in SPSS version 25. Before the analysis of variance (ANOVA), the basic statistical assumptions were verified. These included testing the normality of the data residuals using the Shapiro-Wilk test, checking the homogeneity of variance between treatments using Levene's test, and confirming the independence of errors. Where needed, suitable transformations were conducted to verify that the assumptions were met. A randomized complete block design (RCBD) was used with a split-plot arrangement, considering the treating water stress levels as the main plot factor and fertilization treatments as the subplot factor. Means were then separated using the least significant difference (LSD) test at p= 0.05.

Results and Discussion:

3.1Number of Days from Planting to 50% Male Flowering (days).

The results demonstrate the important influence of irrigation levels, fertilization treatments, and their interaction on the time required to reach 50% male flowering. As shown in Table 2, the shortest duration (53.64 days) was observed with full irrigation (I1), while the longest period (56.76 days) resulted from severe water stress (I3). This delay is attributed to the inhibitory influence of water scarcity on physiological processes mentioned previously. Water stress also enhances cytokinin accumulation, which

causes an obvious delay in senescence and prolongs the vegetative phase.

On the other hand, the shortest duration to flowering (54.43 days) was observed with the full organic treatment (F2), while the unfertilized control (F0) exhibited the longest time. This behavior is expected due to the significant importance of fertilizer for growth speed and indicates the advantage of increasing soil nutrients, specifically nitrogen and phosphorus, in speeding vegetative growth and facilitating earlier transition to the reproductive stage. The addition of fertilization further contributes to hormonal balance and steady flowering. The combination effect proves the significance of appropriate moisture integrated with wealthy organic feeds in improving precocious vegetative vigor and promoting timely reproductive development, where the combination of I1 and F2 supplied the earliest flowering (52.17 days).

Table (2). The impact of using organic fertilizers, chemical fertilizers, and their combination on the duration of male flowering (days) under various water stress conditions.

Mean Water Stress (±SD)	Fertilizer (mean ±SD)					Water Stress
	F_4	**F_3**	**F_2**	**F_1**	**F_0**	
53.64[a] ± 0.45	53.33 ± 3.14	54.15 ± 1.17	52.17 ± 0.40	54.22 ± 1.22	54.34 ± 0.11	I_1
55.27[b] ± 0.88	55.41 ± 10.22	55.19 ± 3.61	54.52 ± 0.82	54.64 ± 3.19	56.57 ± 2.74	I_2
56.76[c] ± 0.21	56.58 ± 6.00	56.73 ± 5.07	56.61 ± 0.94	56.11 ± 3.11	57.75 ± 7.33	I_3
	55.11[ab] ± 1.37	55.36[ab] ± 5.00	54.43[b] ± 1.99	54.99[ab] ± 7.64	56.22[a] ± 8.02	Mean Fertilizer

3.2 Water Stress Physiology

As shown in Table 2, there is an obvious delay for 50% male flowering I3 (56.76) versus I1 (53.64 days) due to water stress, indicating disrupted phenological development. Under drought conditions, plants partially close stomata to save water, minimizing CO_2 uptake and photosynthesis by 30-50%. The partial reduction of stomata leads to reduced carbohydrate formation and transport to the release apical meristem, slowing the transition from the vegetative to the reproductive phase.

Concurrent cytokinin accumulation in leaves (up 25% under stress) slows leaf senescence and prolongs vegetative growth as an adaptive survival strategy. Reduced assimilate provision to floral primordia

further slows tassel initiation, while ABA signaling prioritizes root growth over reproduction. F2 organic treatment showed the fastest flowering (54.43 days) by improving soil moisture retention and maintaining turgor for meristem activity. These physiological constraints demonstrate yield reductions in Tables 4-6, where I3F0 showed maximum developmental delays.

3.3 Leaf Area (cm^2).

There was an obvious relation between the leaf area and the investigated parameters (irrigation, fertilization, and their combination). Full irrigation (I1) provided the largest leaf area, while the smallest was observed with plants under severe water stress (I3). Leaf expansion was minimized because of water stress, due to limiting cell elongation, which limits the formation of new leaves and speeds senescence as an adaptive mechanism to minimize transpiration.

Among different fertilizer types, the highest leaf area (3925.25 cm^2) was obtained by using F3 (40% organic + 60% chemical), which asserts the synergistic impact of organic and chemical fertilizers, where organic fertilizers enhanced soil physical criteria, and the rapid nutrient uptake is obtained from chemical fertilizers. This combination improves chlorophyll content and meristematic cell activity.

Combining irrigation and fertilization leads to the highest leaf area overall (4915.27 cm^2), specifically by combining I1 with F3, indicating that optimal moisture conditions enable plants to completely utilize the advantages of combining fertilization, resulting in strong vegetative growth. The improvement of the results was obtained by F3 (3925 cm^2), which indicates synergistic nutrient dynamics, where rapid N availability for initial cell division/expansion is provided by chemical fertilizers, while organic manure provides sustained P-K release and 15-20% higher soil water-holding capacity (WHC) under drought. Enhance WHC buffers stomatal closure, maintaining turgor for meristematic activity and chlorophyll synthesis. Similar INM trials report 12-18% higher SPAD chlorophyll values with 40:60 organic-chemical blends versus sole chemical, associated with 22% bigger leaf area under 50% water deficit. Thus, F3 optimizes both immediate nutrition and drought resilience, explaining I1XF3's peak (4915 cm^2.(

The full results of the effect of a combination of organic and chemical fertilizers, as well as their interaction with each other, on the leaf area trait under levels of water stress are presented in Table 3.

Table (3). The influence of organic fertilizers, chemical fertilizers, and their combination on the leaf area trait (cm^2) under various levels of Water Stress.

Mean Water Stress (±SD)	Fertilizer (mean ± SD)					Water Stress
	F_4	**F_3**	**F_2**	**F_1**	**F_0**	
3845.92[a] ± 15.11	4225.17 ± 20.00	4915.27 ± 19.34	3177.91 ± 61.07	3900.44 ± 33.45	3010.82 ± 27.01	I_1
3386.20[b] ± 17.66	3858.61 ± 37.00	3455.96 ± 51.09	3113.75 ± 70.88	3660.22 ± 18.68	2842.45 ± 26.00	I_2

3187.71[c] ± 40.06	3544.37 ± 35.25	3404.53 ± 23.11	3196.17 ± 18.65	3278.84 ± 20.75	2514.66 ± 12.38	I_3
	3876.05[b] ± 91.12	3925.25[a] ± 49.58	3162.61[d] ± 28.49	3613.17[c] ± 66.13	2789.31[e] ± 55.00	Mean Fertilizer

3.4 Ear diameter (cm)

Irrigation and fertilization highly influenced the ear diameter. As shown in Table 4, the largest ear diameter (5.18 cm) was achieved by full irrigation (I1), whereas severe stress (I3) gave the smallest (4.49 cm). This reduction under water deficit is primarily

because of decreased photosynthetic productivity and lower translocation of assimilates to reproductive organs.

Using fertilization F3 led to the highest mean ear diameter (6.04 cm), while the smallest was observed with the control F0. This behavior is attributed to the improved nutrient acquisition, where a greater number of kernels per ear occurs when sufficient nutrients are supplied. The combination of I1 with F3 resulted in the highest ear diameter (6.67 cm), confirming our previous conclusions that nutrient-rich conditions and adequate soil moisture jointly enhance the structural development of maize ears.

Table (4). The effect of using organic fertilizers, chemical fertilizers, and their combination on ear diameter (cm) under various levels of water stress conditions.

Mean Water Stress (± SD)	Fertilizer (mean ± SD)					Water Stress
	F_4	**F_3**	**F_2**	**F_1**	**F_0**	
5.18[a] ± 0. 10	6.12 ± 0.11	6.67 ± 0.08	4.81 ± 0.07	4.53 ± 0.14	3.79 ± 0.20	I_1
4.98[b] ± 0.15	5.82 ± 1.01	6.33 ± 0.05	4.66 ± 0.04	4.46 ± 0. 12	3.65 ± 0.03	I_2
4.49[c] ± 0.13	4.94 ± 0.04	5.12 ± 0.01	4.58 ± 0.01	4.3 ± 0.00	3.52 ± 0.09	I_3
	5.63[b] ± 0.02	6.04[a] ± 0.07	4.68[c] ± 0.10	4.43[c] ± 0.06	3.65[d] ± 0.04	Fertilizer Mean

3.5 Number of the Grains per Row (grains row^{-1})

The number of grains per row decreased significantly with increased water stress. Full irrigation (I1) yielded the highest value (26.82 grains row^{-1}), whereas severe stress (I3) yielded the lowest (25.49 grains row^{-1}). Water limitation disrupts pollen viability and silk emergence, leading to incomplete fertilization and higher ovary abortion rates.

The results of the fertilization treatments show that the highest number of grains (27.35 grains row^{-1}) was achieved by using 40% organic + 60% chemical (F3), which could be attributed to two factors, which are the improvement of the soil by phosphorus, as well as the enhancement of floral development under integrated fertilization. The combination of irrigation and fertilization (I1 with F3) achieved the maximum number of grains (27.87), highlighting that integrated nutrient management delivers its greatest benefit when water supply is not limited.

Table (5). The impact of using organic fertilizers, chemical fertilizers, and their combination on the number of grains in the row (grain row^{-1}) under various levels of Water Stress conditions.

Mean Water Stress (± SD)	Fertilizer (mean ± SD)					Water Stress
	F_4	**F_3**	**F_2**	**F_1**	**F_0**	
26.82^{a} ± 0.07	27.62 ± 0.10	27.87 ± 0.06	26.91 ± 0.11	26.88 ± 0.18	24.83 ± 0.33	I_1
26.21^{b} ± 1.01	27.2 ± 0.02	27.68 ± 0.12	25.77 ± 0.15	25.65 ± 0.22	24.74 ± 0.09	I_2
25.49^{c} ± 0.71	26.54 ± 0.30	26.49 ± 0.10	25.44 ± 0.19	25.07 ± 0.08	23.92 ± 0.04	I_3
	27.12^{b} ± 0.14	27.35^{a} ± 0.10	26.04^{c} ± 0.05	25.87^{d} ± 0.43	24.50^{e} ± 0.17	Fertilizer Mean

3.6 Grain Yield (Megagrams ha^{-1})

Increasing water stress resulted in an obvious reduction in grain yield. Specifically, the highest yield (5.09 Mg ha^{-1}) was obtained by full irrigation (I1), while moderate stress (I2) reduced yield moderately, and severe stress (I3) caused a significant reduction (3.73 Mg ha^{-1}) due to restricted nutrient absorption, diminished assimilate production, and impaired grain filling under moisture deficit.

As expected, fertilization highly impacts the crop yield, as shown in Table 6, where the highest yield (5.63 Mg ha^{-1}) was

achieved by the integrated treatment F3, indicating the importance of providing adequate nutrients and improved soil fertility that improves root activity and physiological performance. On the other hand, the lowest yield (3.42 Mg ha^{-1}) was produced by the control F0. The combination of the I1 and F3 led to the highest grain production (6.48 Mg ha^{-1}), emphasizing the positive influence of integrating optimal irrigation with integrated nutrient management to maximize maize productivity under water-scarcity conditions.

Table (6). The impact of using organic and chemical fertilizers and their interaction with each other on the total grain yield (Mg ha^{-1}) under levels of Water Stress.

Mean Water Stress (± SD)	Fertilizer (mean ± SD)					Water Stress
	F_4	**F_3**	**F_2**	**F_1**	**F_0**	
5.09[a] ± 0.74	5.83 ± 0.08	6.48 ± 0.10	4.75 ± 0.11	4.72 ± 0.14	3.65 ± 0.03	I_1
4.84[b] ± 0.62	5.64 ± 0.06	6.11 ± 0.22	4.58 ± 0.16	4.51 ± 0.02	3.37 ± 0.04	I_2
3.73[c] ± 0.40	4.19 ± 0.51	4.29 ± 0.17	3.52 ± 0.08	3.42 ± 0.25	3.25 ± 0.27	I_3
	5.22[b] ± 0.06	5.63[a] ± 0.91	4.28[c] ± 0.13	4.22[c] ± 0.11	3.42[d] ± 0.05	Mean Fertilizer

Conclusion

The findings of this investigation demonstrate the importance of both drought conditions and different fertilizer approaches in influencing maize yield and growth, including the growth duration and crop quality. The best outcomes were achieved by combining 40% organic fertilizer with 60% chemical (treatment F3) with full watering (I1), which highlights how the integration of balanced nutrients with plenty of water boosts output. Simultaneously, the harshest drought conditions paired with zero fertilizer (I3 with F0) resulted in the lowest yields. These findings prove that combining nutrient management with efficient irrigation provides a sustainable strategy to mitigate drought influence and improve maize production in arid and semi-arid regions.

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