STABILITY ANALYSIS AND EVALUATION OF SPRING MAIZE HYBRIDS UNDER DIFFERENT SOWING DATES AND IRRIGATION LEVELS

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Abstract. Genotype × environment interactions represent a major challenge in breeding programs aimed at developing high-yielding, well-adapted cultivars. To achieve more precise selection, it is essential to evaluate both the performance and stability of hybrids across different environments simultaneously. Maize (*Zea mays L.)* is one of the world's most important cereal crops, valued for its high yield potential, genetic diversity, and multifunctional uses in food, feed, and industry. Climate change exacerbates water scarcity by disrupting rainfall, intensifying droughts, thereby boosting evaporation, threatening agriculture and ecosystems. The study aimed to evaluate performance and yield stability of ten maize hybrid cultivars under different spring sowing dates and irrigation levels in Bazian, Kurdistan region-Iraq in spring, 2024. The experimental design was (CRBD) across six environments E1-E6 (three sowing dates SD1-SD3 × two irrigation levels: 2 and 4 L), using 10 hybrid cultivars of both local and introduced species (Kontigos, Koncense, ED 110, DKC 66 64, AGN 720, Jameson, ZPF 59 × un 44 52, ZP 505 × IK8, Abjaro, Al Nahrayn). Stability analysis using Eberhart and Russell's model identified differences between hybrids were highly significant for all parameters (number of ear per plant, number of kernels per ear, 300 kernel weight, kernel yield, total root dry weight, soil surface wetting area and soil moisture depth) except soil surface wetting area and soil moisture depth which were not significant. Despite low stability C9 had high-yielding across all environments (16.088) th^{1}, with (bi 1.513 and S^2di 2.928). The environment with early SD and 4L (E2) consistently produced the highest yields (17.438) th^{-1}.
Keywords: *cultivars, environment, Zea mays L., kernel yield, corn*

Introduction

Maize (*Zea mays* L.) is a globally significant cereal crop with extensive applications in food, feed, and industrial sectors. It is categorized into several types, including dent maize which is used for livestock feed and industrial processing. Advances in breeding techniques and biotechnology have enhanced maize productivity, stress tolerance, and resistance to pests and diseases (Kharazmshahi et al., 2015: Maresma et al., 2019). Maize growth and development are influenced by genetic, environmental, and physiological factors, with stability being key to optimal productivity and stress adaptation (Ogola et al., 2013; Koca and Canavar, 2021). Drought represents the most limiting environmental factor for crop production worldwide, capable of reducing average yields by more than 50% and degrading grain quality across staple cereals such as wheat and maize (Yordanov et al., 2000; Aslam et al., 2015). In Iraq, a combination of extreme heat, declining precipitation, and overdependence on dwindling river flows has intensified agricultural water scarcity. Breeding for stable genotypes with consistent growth and yield under environmental stresses such as drought, combined with

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practices like precision irrigation, can improve resilience. Recently, researchers have attempted to analyze stability for most crops in the Kurdistan region and also in Iraq, the stability of barley and wheat genotypes had significant differences on yield and yield components of barley due to different sowing dates (Abdulla and Mustafa, 2024; Al-Falahi et al., 2021). Timely sowing is crucial for maximizing maize grain and biomass yields, though the optimal sowing date varies by region due to climate and growing season length. Maize requires warm soil for germination, but early sowing is increasingly prioritized to utilize solar radiation, enhance yields, and reduce the need for artificial grain drying. Drip irrigation is one of the most efficient and water-saving irrigation methods worldwide. Drought is one of the major constraints threatening agriculture in Iraq, seriously reducing maize productivity. Although some studies (Abdul, 2023) reported stable yields of certain hybrids under water deficit conditions, this stability often reflects an adaptive trade-off, as drought-tolerant genotypes usually do not reach the same yield potential as high-yielding hybrids grown under adequate water supply. The concept of stability in cultivar evaluation dates back to regional performance trials in 1917 (Scapim et al., 2000; Berzsenyi et al., 2007). Early parametric approaches treated the genotype's response to environmental variation as a simple one-dimensional relationship, using various univariate indices to quantify stability. As a result, a genotype deemed stable under one criterion might be classified as unstable under another, leading to inconsistent results. The primary aim of multi-environment trials (METs) is to assess genotypic performance and characterize genotype × environment interactions (Wricke, 1962) using parameters such as stability variance (Shukla, 1972), regression slope (Finlay, 1963), deviation from regression (Eberhart and Russell, 1966), and the coefficient of determination (Pinthus, 1973). Differences in genotype performance across diverse environments are fundamentally driven by these cultivar and environment interactions (Shrestha et al., 2018).

In the Bazian region/Iraq farmers usually sowing maize in July, particularly during the first half of the month, which require heavy irrigation due to raising temperature. However, in this study, maize hybrids were cultivated in March to early April in three sawing dates, with the aim of relying on rainfall and reducing the need for irrigation, to evaluate the stability analysis and compare yield and yield components of ten hybrid cultivars of maize. Maize yield and stability are highly dependent on both genetic potential and environmental management. Among the management factors, irrigation plays a decisive role, particularly in semi-arid regions where water scarcity is a major constraint. Previous studies have shown that deficit irrigation can reduce yield through limited kernel set and grain filling, while optimal irrigation maximizes biomass and grain production, and excess irrigation may impair root function and nutrient use efficiency.

Materials and methods

Experimental site

The experiment was conducted at Bazian region 35°.578687' N, 45°.148615' E in Sulaimani governorate/Kurdistan-Iraq, during the spring season of 2024 under rainfed plus irrigation levels. Ten introduced and local devising maize hybrid cultivars named (Kontigos, Koncense, ED110, DKC66 64, AGN 720, Jameson, ZPF 59 × un 44 52, ZP 505 × IK8, Abjaro, Al Nahrayn). Hybrids were cultivated in different environments (*Table 1*).

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Experimental design

The experiment was arranged as a randomized complete block design (RCBD) with three replicates per environment. The total area across all environments was approximately 2 100 m², 180 experiment unites (3 sowing date × 2 irrigation level × 3 replicate × 10 hybrids). Spacing between replicates was 1 m, between irrigation treatments 1.25 m, and between sowing dates 1.5 m. Hybrids were spaced 50 cm apart and each was cultivated in four rows, each 2.5 m long. The distance between plant rows and lateral irrigation lines was 70 cm. 12 seeds were sown per row at 20 cm intervals and a depth of 3–4 cm, maize population per hectare (71429). Tensiometers were employed to monitor soil moisture and determine the timing of irrigation treatments. The first irrigation was on 17th May. Diammonium phosphate DAP (18:46:0) was applied at 200 kg ha^{-1} at sowing, and urea (46% N) was applied at 200 kg ha^{-1} during the V5 and V6 vegetative stages according to Ritchie scale. All agronomic practices were carried out as required. On 5th, 11th and 13th of July hybrids of SD1, SD2 and SD3 were harvested respectively. 17th May was the first irrigation because rainfall stopped, irrigation times during all growing season period in each sowing dates SD1, SD2, SD3 were (11, 12, 14) respectively. Irrigation was applied at rates of 2 L or 4 L per plant per occasion, equivalent to 14.3 mm and 28.6 mm per irrigation, respectively, based on a plant density of 71,492 plants ha^{-1}. Depending on sowing date, 11, 12, 14 irrigations were applied during the season, resulting in (157.3, 314.5, 171.6 343.2, 200.2, 400.4) mm water used WU. Irrigation stopped 10 days before harvesting. The accumulated GDU values differed among sowing dates, with SD1 (10 March) recording 1564 units, SD2 (20 March) 1536 units, and SD3 (3 April) 1503 units. These differences indicate that earlier sowing provided a longer thermal time for crop development, which likely contributed to improved yield performance compared with later sowing.10 plants samples of each row were measured (40 plants per an experiment unite).

Statistical analysis

Analysis of variance (ANOVA) was conducted for each environment, followed by a pooled analysis across environments. Stability was assessed using three parametric methods: mean performance, joint regression coefficient (bi), and deviation from regression (S^2di). A cultivar was considered stable if it exhibited a regression coefficient of unity (bi = 1) and a non-significant deviation from regression (S^2di = 0), indicating consistent performance across environments. Mean comparisons were performed using Duncan's multiple range test (Duncan, 1995). Yield stability for each cultivar was evaluated by regressing the mean yield of individual cultivars against the environmental index and calculating deviations from regression, as proposed by Eberhart and Russell (1966). The regression coefficient (bi) reflected the cultivar's responsiveness to environmental variations. Statistical analyzes were performed using OPSTAT, a software developed by CCS Haryana Agricultural University, Hisar, India (http://14.139.232.166/opstat/index.asp). Although the experiment was conducted at one location, the term "environment" in our analysis referred to the combinations of sowing dates and irrigation levels. These combinations created six distinct environments (E1–E6), which were treated as separate experimental conditions in the statistical analysis. In OPSTAT, the factorial model considered irrigation level, sowing date, genotype, and their interactions, so the genotype × environment interaction reflects the response of hybrids across these management-defined environments rather than across multiple geographic sites (*Table 1*).

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Table 1. *Agro-climatic characteristics of the environments tested in Bazian location, Kurdistan region, Iraq, 2024*

Months	**Temp. °C**		**Rainfall mm**	**Soil properties**		**Environments**		
	Max	**Min**						
January	12.0	-2.4	81.1	Texture	Silty clay	**Code**	**SD**	**I. Q.**
February	11.0	2.7	325.9	PH	8.18	E1	March 10^{th}	2 L
March	13.5	5.0	103.8	O. M.(g/kg)	17.9	E2	March 10^{th}	4 L
April	23.0	11.0	35.1	% Sand	6.11	E3	March 20^{th}	2 L
May	29.7	11.0	83.4	% Silt	41.05	E4	March 20^{th}	4 L
June	34.5	25.7	0	% Clay	52.84	E5	April 3^{rd}	2 L
July	45.8	38.0	0	EC dS m^{-1}	0.25	E6	April 3^{rd}	4 L
				N %	0.13			
				CaCO3(g/kg)	225			
Total			**629.3**	Na^{+} (ppm)	2			

O.M: organic matter, SD: sowing date, I.Q: irrigation quantity

Studied parameters

No. of ears per plant: It was count as the number of ears per each plant.

No. of kernels per ear: All kernels were counted per ear.

300-kernels weight (g): The weight of 300-kernels samples was recorded at 15% of moisture content.

Total kernels yield per hectare (th^{-1}): This calculated according this formula: Total kernels yield per hectare = kernels yield of one plant × plant density (number of plants per hectare)/1000000.

Total root dry weight (g): It was determined by drying fresh root samples at 70°C until constant weight (checked at 24-h intervals) and weighing them with a digital balance.

Soil surface wetting area (cm^2): It was measured during irrigation events. The wetted radius (r) was determined using a ruler (scale) from the emitter to the edge of the visibly wetted soil surface. The wetting area was then calculated using the circular area formula:

$$\text{Area} = \pi r^2 \quad \text{(Eq.1)}$$

where A = surface wetting area (cm²) and r = measured wetted radius (cm).

Soil moisture depth (cm): It was determined after irrigation by excavating the soil until the last point of visible water penetration. The depth of the wetted zone was then measured vertically from the soil surface down to the bottom of the wetted profile using a ruler (scale).

Results

Table 2 shows the ANOVA results that cultivar, environment, and their interactions significantly influenced all traits level ($P \leq 0.01$), effects on most measured traits, including No of ear. plant^{-1} (NEP), No kernel ear^{-1} (NKY), 300-kernel yield (300 KY), and total root dry weight (TRDW) except soil surface area (SSA) and soil moisture depth (SMD) which were no significant. Different sowing dates (SD) played a crucial role as

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(Zhu et al., 2022) stated that delayed planting effect growth, development, and yield outcomes. However, for the same parameter irrigation levels illustrated that reduction ratio by 35% between 2 L (E1, E3, E3) and 4 L (E2, E4, E6). In addition, for SMD parameter there was reduction ratio between environments by 51% between irrigation levels 2 L and 4 L. Significant interactions cultivar × environment indicate that cultivars responded differently across environments, affecting trait stability and performance (Buriro et al., 2015). In addition, In the same table, the ANOVA for stability (Eberhart and Russell Model) of the mean squares for cultivars, environments, and their interactions appeared highly significant ($P < 0.01$) for all characters. These results are in agreement with those previously reported by Maresma et al. (2019). Cao et al. (2024) likewise observed significant differences among cultivars for all studied traits across each of the three individual environments. Cultivar × environment interactions were also highly significant for every character, indicating that the behavior of some hybrids varies according to the environmental conditions in which they are grown, and that the contribution of cultivars to improved crop yield and its components is closely dependent on the growing environment.

Table 2. *Analysis of variance for the studies characters for each environment and across six environments for 10 maize hybrid cultivars in Bazian/Kurdistan Region-Iraq, growing season 2024*

S.O.V.		**d.f**	**Mean squares**						
			No. ear/plant NEP	**No. Kernel/ear NKE**	**300 Kernel weight TGW**	**Kernel yield KY**	**Total root dry weight TRDW**	**Moisture depth SMD**	**Soil surface wetting area SSWA**
E1	Cultivar	9	0.058**	3312.4**	133.441**	5.521**	10.531**	0.074$^{n.s}$	50.057$^{n.s}$
	error	18	0.004	103.750	0.763	0.077	0.006	0.033	32.131
E2	C	9	0.070**	16,987.2**	119.680**	38.302**	13.865**	0.017$^{n.s}$	289.947$^{n.s}$
	e	18	0.002	205.2	0.782	0.221	0.011	0.009	122.512
E3	C	9	0.084**	2210.8**	100.015**	11.430**	10.065**	0.004$^{n.s}$	31.822$^{n.s}$
	e	18	0.002	232.400	0.507	0.107	0.007	0.004	42.779
E4	C	9	0.026**	12,871.9**	85.745**	19.908**	10.469**	0.008$^{n.s}$	116.110$^{n.s}$
	e	18	0.001	184.373	0.227	0.106	0.050	0.004	69.586
E5	C	9	0.086**	6511.2**	90.821**	8.580**	9.798**	0.009$^{n.s}$	10.671$^{n.s}$
	e	18	0.003	153.552	0.224	0.057	0.017	0.004	5.532
E6	C	9	0.069**	14,090.6**	65.355**	53.746**	9.884**	0.001$^{n.s}$	246.799$^{n.s}$
	e	18	0.002	204.296	0.231	0.055	0.007	0.004	117.758
ANOVA for stability (Eberhert and Russel model)									
Cultivar (C)		9	0.097**	16,050.9**	186.947**	36.969**	21.433**		
Environment (E)		5	0.085**	152,102.7**	1588.114**	99.513**	34.680		
C X E		45	0.007**	522.1**	2.281**	1.772**	0.032*		
E + C X E		50	0.015	15,680.2	160.864	11.546	3.497		
E (Liner)		1	0.427**	760,513.5**	7940.568**	497.567**	173.399**		
E X C (Lin)		9	0.014**	1324.4**	4.080**	3.522**	0.097**		
Pooled deviation		40	0.004**	289.381**	1.648**	1.201**	0.014**		
Pooled error		108	0.002	180.591	0.456	0.104	0.015		

*Significant ($P \leq 0.05$) **Highly significant ($P \leq 0.01$)

Figure 1 illustrates significant variation among cultivars across environments (E1–E6) for the number of ears per plant. In E1, the lowest mean number of ears per plant was observed in C3 and C4 (1.13 each), while the highest value was recorded in C9 (1.53),

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although it did not differ significantly from C5 (1.47), C6 (1.47), C7 (1.43), C8 (1.43), or C10 (1.43). In E2, C4 (1.17) and C3 (1.47) had the lowest means, while C9 showed the highest mean (1.67), which was significantly greater than most cultivars but statistically similar to C5 (1.67) and C6 (1.67). In E3, the lowest means were recorded in C4 (1.07) and C3 (1.20), while the highest was found in C7 (1.53), which was not significantly different from C5 (1.53), C6 (1.53), and C9 (1.57). In E4, the lowest means were in C4 (1.30) and C2 (1.30), while the highest value was in C9 (1.70), which was significantly greater than most other cultivars but statistically similar to C5 (1.40), C6 (1.40), C7 (1.47), and C8 (1.47). In E5, C3 and C4 both had the lowest mean values (1.10), whereas the highest was observed in C9 (1.53), though it was not significantly different from C5 (1.17), C6 (1.16), and C7 (1.17). Finally, in E6, C4 (1.17) and C2 (1.37) recorded the lowest values, while C9 again showed the highest mean (1.70), which was significantly higher than most cultivars but not different from C5 (1.47), C6 (1.47), C7 (1.47), and C8 (1.47).

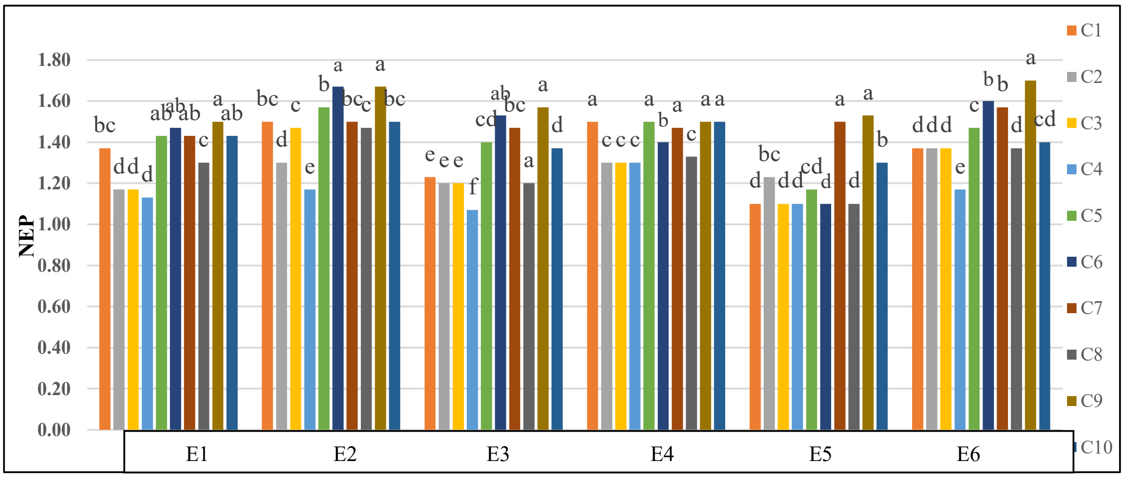

Figure 1. *Means of the No. Ear per plant of 10 hybrid cultivars of maize that tested in six Environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

Figure 2 shows significant variation among cultivars across environments (E1–E6) for the number of kernels per ear. In E1, the lowest kernel numbers per ear were recorded by C3 (529.47) and C4 (496.56), which were not significantly different from each other, while the highest value was observed in C9 (635.80), though it did not differ significantly from C5 (577.95), C6 (586.15), or C7 (581.91). In E2, C4 had the lowest mean (496.56), but it was not significantly different from C3 (701.23), whereas the highest values were recorded in C9 (922.23), C6 (862.97), C5 (838.60), and C1 (795.01). In E3, the lowest means were in C3 (479.72), C4 (488.08), and C8 (488.99), while C9 (832.51) had the highest value, statistically similar to C5 (509.85), C6 (528.75), and C7 (854.58). In E4, the lowest kernel numbers were recorded by C4 (566.80) and C3 (603.79), which were not significantly different, whereas the highest value was found in C7 (707.17), which was significantly greater than all other cultivars. In E5, C3 had the lowest mean (410.75), while the highest values were obtained by C6 (514.51), C9 (547.04), and C5 (480.50). In E5, C3 had the lowest mean (410.75), while the highest values were obtained by C6

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(514.51), C9 (547.04), and C5 (480.50). Finally, in E6, the lowest mean was observed in C7 (480.55), whereas the highest values were recorded in C1 (609.41), C2 (586.86), C9 (706.11), and C10 (615.15), with no significant differences among them.

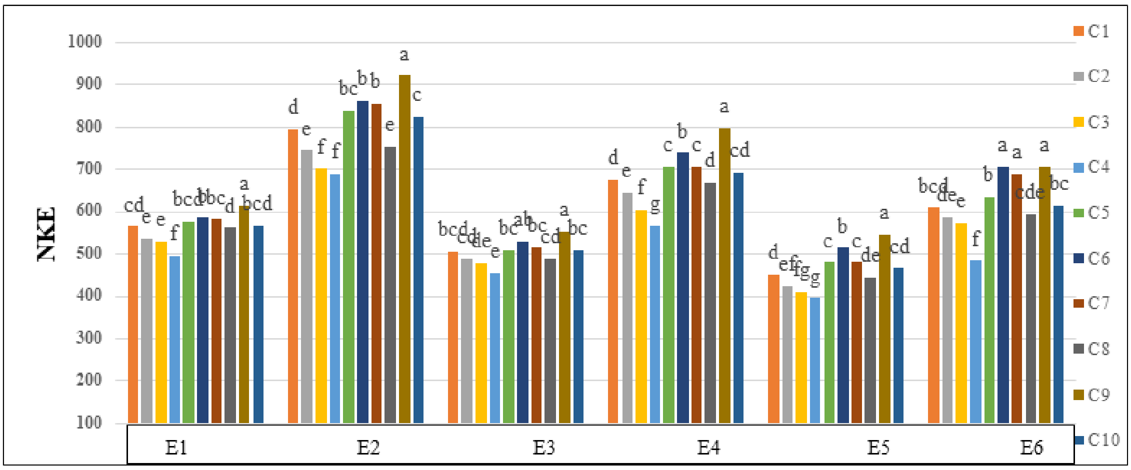

Figure 2. *Means of the No. kernel per ear of 10 hybrid cultivars of maize that tested in six environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

Figure 3 shows the significant variation among cultivars across environments (E1–E6) for the 300 KW cultivars. In E1, the lowest 300-kernel weight was recorded by C4 (46.87 g), while the highest was in C9 (71.91 g), which was significantly greater than most other cultivars but not different from C1 (55.49 g), C2 (51.53 g), and C3 (52.88 g). In E2, C4 had the lowest value (66.98 g), whereas C9 produced the highest mean (87.49 g), statistically similar to C5 (82.22 g), C7 (82.16 g), and C10 (79.69 g). In E3, the lowest value was obtained by C4 (44.22 g), while the highest mean was in C9 (62.63 g), which did not differ significantly from C7 (54.73 g), C5 (51.04 g), and C10 (49.59 g). In E4, C4 again showed the lowest mean (44.07 g), whereas C7 recorded the highest value (76.80 g), which was significantly greater than most cultivars but statistically similar to C5 (74.78 g), C10 (74.13 g), and C9 (80.41 g). In E5, the lowest mean was in C4 (39.37 g), while the highest was obtained by C9 (56.43 g), which was significantly greater than all cultivars except C7 (53.01 g). Finally, in E6, the lowest mean value was observed in C4 (60.40 g), whereas the highest was recorded by C9 (74.99 g), which was significantly higher than most cultivars but not different from C5 (68.10 g), C7 (68.56 g), and C10 (66.76 g).

Figure 4 shows that means of 300 KY were highly significant ($P \leq 0.01$) among the ten cultivars across six environments. In E1, the lowest kernel yield was recorded in C4 (10.53 t ha^{-1}), while the highest was in C6 (14.15 t ha^{-1}), which was not significantly different from C5 (13.39 t ha^{-1}), C7 (13.61 t ha^{-1}), or C1 (12.90 t ha^{-1}). In E2, C4 again had the lowest yield (12.47 t ha^{-1}), whereas the highest was obtained by C6 (22.95 t ha^{-1}) and C9 (23.89 t ha^{-1}), both of which were significantly greater than all other cultivars. In E3, the lowest yield was observed in C4 (7.55 t ha^{-1}), while the highest was in C6 (12.19 t ha^{-1}), which did not differ significantly from C7 (12.10 t ha^{-1}) or C9 (12.71 t ha^{-1}). In E4, the lowest value was again found in C4 (6.51 t ha^{-1}), while the highest mean yield was obtained by C6 (13.97 t ha^{-1}), which was significantly greater than most cultivars but not different from C7 (13.64 t ha^{-1}), C8 (10.35 t ha^{-1}), or C9 (14.38 t ha^{-1}). In E5, the lowest kernel yield

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was recorded in C4 (6.36 t ha^{-1}), while the highest was achieved by C6 (13.08 t ha^{-1}), statistically similar to C7 (9.69 t ha^{-1}) and C9 (10.85 t ha^{-1}). Finally, in E6, the lowest mean was in C4 (6.65 t ha^{-1}), whereas the highest yield was recorded in C6 (17.97 t ha^{-1}) and C9 (20.50 t ha^{-1}), both of which were significantly greater than all other cultivars.

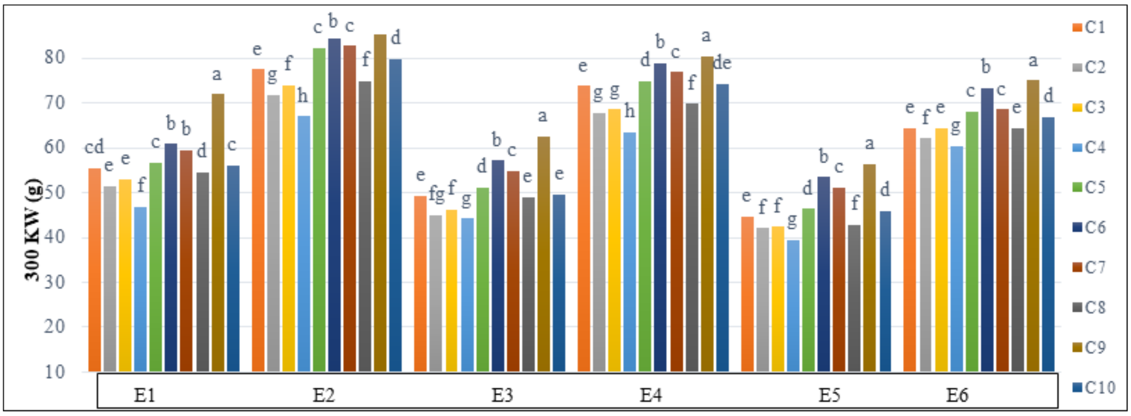

Figure 3. *Means of the 300 kernel weight of 10 maize hybrid cultivars of that tests in six environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

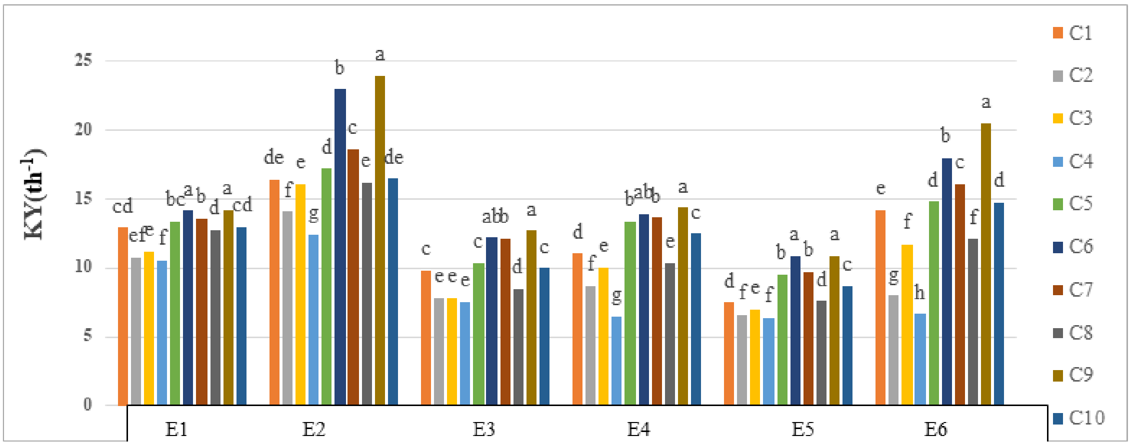

Figure 4. *Means of the kernel weight of 10 maize hybrid cultivars of that tests in six environments in Bazian location, Kurdistan region-Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

Figure 5 shows the mean of TRDW were highly significant ($P \leq 0.01$) for ten cultivars across six environments. In E1, the lowest root dry weight was observed in C4 (15 g), while the highest was in C9 (23 g), which was significantly greater than most cultivars but not different from C7 (20 g), C5 (20 g), or C8 (20 g). In E2, C4 again had the lowest mean (17 g), whereas C9 recorded the highest value (27 g), which was significantly greater than all other cultivars. In E3, C4 (15 g) and C3 (15 g) showed the lowest means, while the highest was in C9 (23 g), which was statistically similar to C7 (18 g), C5 (18 g), and C6 (19 g). In E4, the lowest root dry weight was obtained by C4 (15 g), while the

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highest was in C9 (24 g), which was significantly greater than most cultivars but not different from C7 (21 g) or C6 (21 g). In E5, the lowest mean was in C4 (15 g), while the highest was again in C9 (23 g), which was statistically similar to C7 (19 g), C5 (18 g), and C6 (19 g). Finally, in E6, the lowest root dry weight was observed in C4 (17 g), while the highest was recorded in C9 (23 g), which was significantly greater than most cultivars but not different from C7 (21 g), C5 (19 g), or C6 (19 g). Same parameter irrigation levels illustrates that reduction ratio by 15% between 2 L (E1, E3, E3) and 4 L (E2, E4, E6). In addition, there was reduction ratio between SD1 and SD3 by 13%, and 9% between SD1-SD2 and also SD2-SD3 was 6%.

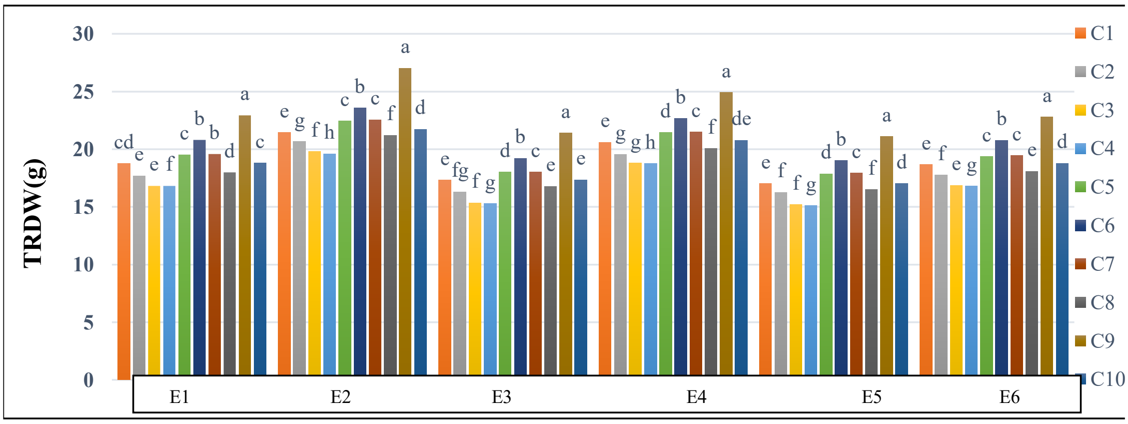

***Figure 5.** Means of total root dry weight (g) of 10 maize hybrid cultivars that tests in six environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

Figure 6 presents means of SSWA (cm²) were not significant among ten maize cultivars across six environments. In (E1), C5 (405.90) and C4 was lowest (398.75). In E2, C5 (618.99) and C4 (595.73). In (E3), C5 (368.49) and C6 (363.97). For E4, C10 (490.40) and C4 (358.56). In (E5) C3 (363.05 cm²) and C4 (358.58 cm²). In E6, C5 (436.75 cm²) and C9 (428.60).

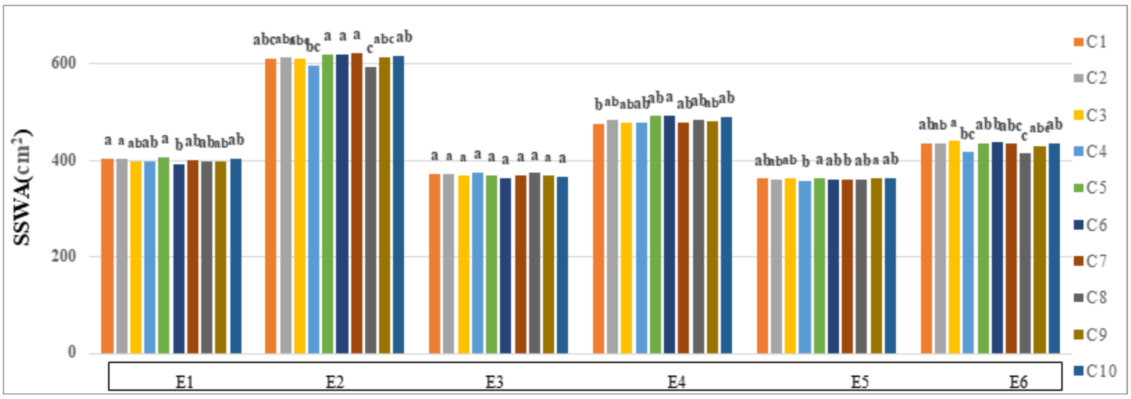

***Figure 6**. Means of soil surface wetting area (cm^2) of 10 maize hybrid cultivars that tests in six Environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

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Figure 7 shows that mean SMD (cm) was no significant ($P \leq 0.01$) among the ten cultivars across six environments. The highest and lowest means in each environment were as follows: in E1, C8 (25.76 cm) and C2 (25.26 cm); in E2, C8 (38.41 cm) and C10 (38.08 cm); in E3, C7 (25.27 cm) and C9 (25.13 cm); in E4, C6 (38.25 cm) and C1 (38.08 cm); in E5, C5 (25.29 cm) and C8 (25.10 cm); and in E6, C2/C4 (38.16 cm) and C10 (38.10 cm). In contrast, significant differences were observed between environments, with mean SMD varying substantially across environments.

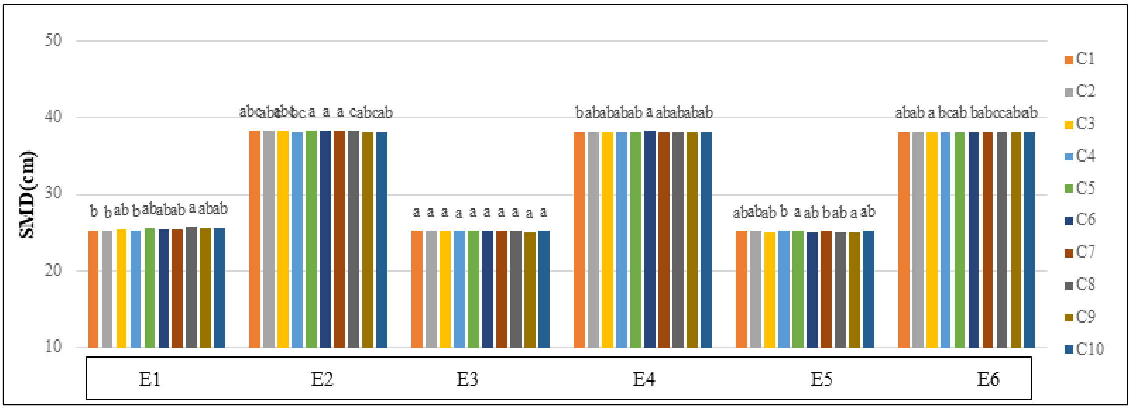

Figure 7. *Means of soil moisture depth (cm) of 10 maize hybrid cultivars that tests in six Environments in Bazian location, Kurdistan region- Iraq, growing season 2024. Values followed by the same letter are not significantly different using Duncan's multiple range test (Duncan's MRT)*

No. ear per plant

Table 3 shows that differences in NEP were highly significant among the ten maize hybrids tested across six environments. Cultivar C9 achieved the highest overall mean (1.578), reflecting strong performance and adaptability, followed closely by C7 (1.489) and C6 (1.461). This result is in agreement with Alam et al. (2021), who recorded the highest NKE (639.23) under early sowing. In contrast, cultivar C4 recorded the lowest overall mean (1.156), indicating limited productivity across sites. Examining individual environments, C9 consistently ranked among the top performers, with the highest mean in E6 (1.700) and E2 (1.667). Conversely, C4 frequently had the lowest means, such as in E3 (1.067) and E5 (1.100). Early sowing promotes ear development by ensuring favorable temperature and moisture conditions, while delayed sowing increases exposure to heat and drought stress, reducing ear formation and increasing the risk of ear abortion (Mekonnen et al., 2021). The regression coefficients (bi) and deviations from regression (S^2di) showed that C5 and C6 combined high means with good stability, while C4 exhibited both low productivity and less consistent performance. These results highlight C9 and C6 as promising cultivars for environments with variable conditions, while C4 appears less suited for broad adaptation. These findings agree with Buriro et al. (2015), who reported that the earliest sowing date produced the highest NEP (1.4). In contrast, Alam et al. (2020) observed the maximum NEP (1.7) under timely sowing compared with early sowing. Regression coefficients (bi) for ear number ranged from 1.156 (C4) to 1.578 (C9), with all bi > 1, indicating that hybrids generally responded more strongly in high-yielding environments. Deviations from regression (S^2di) varied from 0.001 (C10) to 0.566 (C9), where low S^2di denotes consistent, predictable performance across sites. C4

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(bi = 1.156) was the closest to the ideal stability (IS), while C10 with the smallest S²di (0.001) showed the most stable behavior.

Table 3. *Means of cultivars, environments and CX E interaction of the no. ear per plant performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	$S^2{}_{di}$
C1	1.367^{hij}	1.5^{def}	1.233^{kl}	1.5^{def}	1.1^{no}	1.367^{hij}	1.344^{bcd}	1.526	0.005
C2	1.167^{lmn}	1.3^{jk}	1.2^{lm}	1.3^{jk}	1.233^{kl}	1.367^{hij}	1.261^{de}	0.530	0.003
C3	1.167^{lmn}	1.467^{efg}	1.2^{lm}	1.3^{jk}	1.1^{no}	1.367^{hij}	1.267^{de}	1.417	0.001
C4	1.133^{mno}	1.167^{lmn}	1.067^{o}	1.3^{jk}	1.1^{no}	1.167^{lmn}	1.156^{e}	0.485	0.005
C5	1.433^{fgh}	1.567^{cd}	1.4^{ghi}	1.5^{def}	1.167^{lmn}	1.467^{efg}	1.422^{bc}	1.408	0.002
C6	1.467^{efg}	1.667^{ab}	1.533^{cde}	1.4^{ghi}	1.1^{no}	1.6^{bc}	1.461^{ab}	1.846	0.013
C7	1.433^{fgh}	1.5^{def}	1.467^{efg}	1.467^{efg}	1.5^{def}	1.567^{cd}	1.489^{ab}	0.154	0.002
C8	1.3^{jk}	1.467^{efg}	1.2^{lm}	1.333^{ij}	1.1^{no}	1.367^{hij}	1.294^{cde}	1.359	0.000
C9	1.5^{def}	1.667^{ab}	1.567^{cd}	1.5^{def}	1.533^{cde}	1.7^{a}	1.578^{a}	0.566	0.005
C10	1.433^{fgh}	1.5^{def}	1.367^{hij}	1.5^{def}	1.3^{jk}	1.4^{ghi}	1.417^{bc}	0.710	0.001
Means	1.3^{bc}	1.5^{a}	1.3^{bc}	1.4^{ab}	1.2^{c}	1.4^{ab}			

bi: Regression coefficient, S²di: Deviation from regression

Number of kernels per ear

Table 4 shows that differences in NKE were highly significant among ten maize hybrids tested across six environments. Cultivar C9 had the highest mean kernel number (706.10), followed by C8 (585.46) and C7 (638.22), demonstrating strong reproductive performance. NKE in maize is strongly influenced by water availability, particularly during flowering and grain filling, where adequate moisture ensures proper silk emergence, pollen viability, and fertilization to support kernel set. In contrast, cultivar C4 consistently recorded the lowest mean (514.91), reflecting limited productivity across environments. Notably, in Environment 2 (E2), C9 achieved the highest value (922.42), while C4 had the lowest (690.37). A similar trend was observed in Environment 6 (E6), where C9 again ranked first (706.10) and C4 last (484.17). These results agree with Akçalı and Gözübenli (2023), who reported a mean of 534 kernels per ear. Deviations from regression (S²di) ranged from 0.617 (C7 and C9) to 1.316 (C4), with low S²di reflecting predictable, linear performance across sites and high values signaling erratic behavior. C7 (bi = 0.974) and C6 (bi = 1.036) were the closest to the ideal stability (IS) of bi = 1 and S²di = 0, while C7 and C9 with the smallest S²di (0.617) exhibited the most consistent NKE performance.

300 Kernel weight (g)

Table 5 shows that differences in 300-kernel weight (300 KW) were highly significant among ten maize hybrids across six environments. Environment 2 (E2) produced the highest mean weight (78.13 g), indicating that the combination of early sowing and 4 L irrigation was most favorable for kernel development. This was followed by E4 (72.81 g), which also supported relatively high kernel weight. In contrast, E5 had the lowest mean 300 KW (46.46 g), likely due to moisture stress, while E3 also showed comparatively low values (50.88 g). E1 and E6 produced intermediate means (56.62 g and 66.75 g,

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respectively), reflecting moderate growing conditions. These differences highlight that environmental conditions and sowing dates had a significant effect on 300 KW, with E2 and E4 being most conducive to higher kernel weight, while E5 was clearly the most limiting.

Table 4. *Means cultivars, environments and C X E interaction of No. kernel per ear performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments.*

	E1	E2	E3	E4	E5	E6	Means	(bi)	$S^2{}_{di}$
C1	565.32^{opq}	795.013^{e}	506.827^{uvwx}	674.933^{h}	452.427^{A}	609.413^{kl}	600.656^{cde}	0.600	0.656
C2	536.64^{rst}	745.547^{f}	488.08^{wxyz}	644.747^{i}	424.267^{BC}	586.867^{lmno}	571.024^{ef}	0.746	1.264
C3	529.467^{stu}	701.227^{g}	479.72^{yz}	603.787^{klm}	410.747^{CD}	573.013^{nop}	549.66^{fg}	0.746	0.647
C4	496.56^{vwxy}	690.373^{gh}	456.027^{A}	566.8^{opq}	395.587^{D}	484.167^{xyz}	514.919^{g}	0.767	1.316
C5	577.947^{nop}	838.6^{cd}	509.853^{uvw}	706.213^{g}	480.507^{yz}	633.787^{ij}	624.484^{bcd}	0.879	0.887
C6	586.147^{lmno}	862.967^{b}	528.747^{stu}	738.427^{f}	514.507^{tuv}	705.173^{g}	655.994^{ab}	1.036	0.677
C7	581.907^{mno}	854.58^{bc}	515.493^{tuv}	707.173^{g}	480.56^{yz}	689.547^{gh}	638.21^{bc}	0.974	0.897
C8	561.973^{opq}	752.68^{f}	488.987^{wxyz}	670.027^{h}	445.253^{AB}	593.827^{klmn}	585.458^{def}	0.849	0.735
C9	613.733^{jk}	922.247^{a}	553.507^{pqr}	796.8^{e}	547.04^{qrs}	706.107^{g}	689.906^{a}	1.076	0.617
C10	567.733^{opq}	824.4^{d}	509.12^{uvw}	691.987^{gh}	466.987^{zA}	615.147^{jk}	612.562^{cd}	0.868	0.717
Means	561.74d	798.76a	503.64e	680.09b	461.79e	619.70c			

bi: Regression coefficient, S^2di: Deviation from regression

Table 5. *Means hybrid cultivars, environments and C X E interaction of 300 kernel weight (g) performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	$S^2{}_{di}$
C1	55.493^{tu}	77.45^{f}	49.223^{y}	73.757^{gh}	44.723^{B}	64.477^{n}	60.854^{de}	1.050	0.970
C2	51.53^{x}	71.817^{i}	45.087^{AB}	67.697^{klm}	42.05^{C}	62.07^{p}	56.708^{f}	0.974	0.339
C3	52.88^{w}	73.84^{gh}	46.25^{z}	68.493^{k}	42.35^{C}	64.303^{n}	58.019^{f}	1.008	0.595
C4	46.867^{z}	66.977^{lm}	44.223^{B}	63.51^{no}	39.377^{D}	60.4^{qr}	53.559^{g}	0.903	2.786
C5	56.733^{s}	82.223^{c}	51.037^{x}	74.78^{g}	46.377^{z}	68.107^{kl}	63.209^{cd}	1.117	0.333
C6	60.82^{q}	84.317^{b}	57.17^{s}	78.823^{e}	53.453^{vw}	73.407^{h}	67.998^{b}	0.996	1.039
C7	59.41^{r}	82.657^{c}	54.727^{u}	76.803^{f}	51.03^{x}	68.56^{k}	65.531^{bc}	0.996	1.315
C8	54.453^{uv}	74.923^{g}	48.893^{y}	69.723^{j}	42.773^{C}	64.447^{n}	59.202^{ef}	0.992	0.415
C9	71.907^{i}	87.493^{a}	62.627^{op}	80.413^{d}	56.427^{st}	74.993^{g}	72.31^{a}	0.884	7.040
C10	56.153^{st}	79.693^{de}	49.587^{y}	74.13^{gh}	46.003^{zA}	66.76^{m}	62.054^{d}	1.080	0.129
Means	56.624^{d}	78.138^{a}	50.882^{e}	72.812^{b}	46.456^{f}	66.752^{c}			

bi: Regression coefficient, S^2di: Deviation from regression

Deviation from regression (S^2di) ranged from 0.129 (C10) to 7.040 (C9), where low S^2di indicated predictable, linear responses across environments and high values reflected erratic cultivar × environment behavior. Cultivars C6 and C7, with regression coefficients close to unity (bi = 0.996) and relatively low S^2di, were the closest to the ideal stability (IS) and thus exhibited the most consistent, broadly adapted performance. Cultivar C10 had the smallest S^2di (0.129), making it the most predictably stable, while C5 (0.333) also demonstrated reliable performance across environments. These results are consistent with those of Dahmardeh (2012) and Kharazmshahi et al. (2015), who reported kernel weights

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of 117.7 g and 113 g, respectively. Ample moisture during grain filling sustains photosynthesis, delays leaf senescence, and extends assimilate translocation, thereby increasing 300-kernel weight. In contrast, early sowing under moderate temperatures and sufficient water lengthens the filling period and enhances kernel weight, whereas late sowing heightens heat and drought stress, reducing kernel weight.

Kernel yield (th^{-1})

Table 6 shows that differences in kernel yield (KY) were highly significant among ten maize hybrids across six environments. The environmental means ranged from 8.4 t ha^{-1} in E5 to 17.4 t ha^{-1} in E2, reflecting substantial variability due to differences in sowing dates and irrigation levels. Environments E2 (17.4 t ha^{-1}) and E4 (11.4 t ha^{-1}) favored better kernel development, likely due to more optimal moisture and temperature conditions, whereas E5 (8.4 t ha^{-1}) and E3 (9.9 t ha^{-1}) were less favorable, likely due to stress factors such as late sowing or reduced irrigation. The most productive hybrid across all environments was C9, with a mean yield of 16.088 t ha^{-1}, achieving its highest values in E2 (23.893 t ha^{-1}) and E6 (20.503 t ha^{-1}). These findings are consistent with Zhu et al. (2022), who reported that delayed sowing significantly reduced 300-kernel weight from 346.5 g to 335.3 g, leading to lower yield. Similarly, Alam et al. (2020) reported that shifting the sowing date earlier by one-week reduced KY by 0.663 t ha^{-1}. Regression coefficients (bi) for kernel yield ranged from 0.618 (C4) to 1.513 (C9), where bi > 1 indicates heightened responsiveness in favorable environments and bi < 1 signals relative steadiness under less favorable conditions. Deviations from regression (S^2di) varied from 0.071 (C3) to 3.362 (C4), with low S^2di denoting predictable performance across sites and high values reflecting erratic cultivar × environment interactions. C1 (bi = 0.997) and C8 (bi = 0.980) were closest to the ideal stability (bi = 1, S^2di = 0), while C3, with the smallest S^2di (0.071), exhibited the most consistent and broadly adapted yield performance. Early sowing dates combined with regulated irrigation boosted kernel yield by lengthening the growing season, enhancing leaf area and carbohydrate production for grain filling. This shift also placed flowering and grain-filling into cooler, moisture-reliable periods, reducing flower abortion and incomplete kernel development. Stable irrigation-maintained photosynthesis and nutrient uptake, prevented waterlogging, and supported balanced source–sink dynamics. Together, these effects extended phenology, enhanced root vigor, and maximized NEP, NKE, and 300 KW (*Tables 3–5*), which in turn contributed to high kernel yield. Similarly, Dahmardeh (2012) reported that KY significantly increased to 8.3 t ha^{-1} under optimal sowing compared with delayed sowing.

Total root dry weight (g)

Table 7 shows that mean total root dry weight (TRDW) varied significantly across environments, reflecting the influence of sowing date and irrigation. The highest mean was observed in E2 (22.009 g plant^{-1}) under early sowing, followed by E4 (20.914 g plant^{-1}) and E6 (18.938 g plant^{-1}) under full irrigation at later sowing dates. The lowest means occurred in E5 (17.306 g plant^{-1}) and E3 (17.508 g plant^{-1}), both under limited irrigation (2 L), highlighting water availability as the main factor affecting root biomass. Even in early sowing (E1), restricted irrigation reduced root dry weight (18.975 g plant^{-1}). These findings agree with Lawal et al. (2020), who reported that sufficient moisture during early growth promotes larger root systems. While water

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supports cell expansion and elongation, delayed sowing shortens the vegetative period and limits root development despite irrigation (Maresma et al., 2019; Sandeep Varma et al., 2014). Among cultivars, C9 produced the highest and most stable root biomass, making it well suited to drought-prone environments such as E1 and E3. Although slightly variable (S^2di = 0.092), its consistent performance is valuable. C5, C6, and C10 combined high stability (low S^2di) with adaptability (bi ≈ 1), indicating suitability for both stress and non-stress conditions. In contrast, C4 and C2 were less responsive and lower yielding, fitting low-input systems where stability is prioritized over maximum productivity. Most cultivars showed low deviations (e.g., C1, C4, C8), confirming acceptable stability across conditions. Overall, deviations from regression (S^2di) ranged from 0.003 (C3, C5, C7) to 0.092 (C9), with values near zero reflecting highly predictable performance. C10 (bi = 0.999) and C8 (bi = 0.992) were closest to the ideal stability (bi = 1, S^2di = 0), while C3, C5, and C7, with the lowest S^2di (0.003), exhibited the most consistent TRDW stability across environments.

Table 6. *Means cultivars, environments and C X E interaction of kernel yield (th^{-1}) performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	S^2 di
C1	12.9^{mn}	16.427^{g}	9.813^{vw}	11.02^{rs}	7.47^{zA}	14.21^{ij}	11.973^{cde}	0.997	0.476
C2	10.743^{rst}	14.06^{ijk}	7.837^{z}	8.677^{x}	6.57^{BC}	8.01^{yz}	9.316^{fg}	0.759	1.902
C3	11.177^{r}	16.1^{g}	7.86^{z}	10.01^{uvw}	7.043^{AB}	11.737^{q}	10.654^{efg}	1.022	0.071
C4	10.533^{stu}	12.467^{nop}	7.547^{zA}	6.51^{BC}	6.36^{C}	6.653^{BC}	8.345^{g}	0.618	3.362
C5	13.393^{lm}	17.187^{f}	10.337^{tuv}	13.363^{lm}	9.503^{w}	14.793^{h}	13.096^{bcd}	0.878	0.443
C6	14.147^{ijk}	22.947^{b}	12.187^{opq}	13.903^{ijkl}	10.837^{rst}	17.97^{e}	15.332^{ab}	1.376	1.042
C7	13.61^{kl}	18.627^{d}	12.103^{pq}	13.64^{jkl}	9.687^{w}	16.063^{g}	13.955^{abc}	0.963	0.454
C8	12.783^{n}	16.203^{g}	8.44^{xy}	10.353^{tuv}	7.58^{zA}	12.067^{pq}	11.238^{def}	0.980	0.445
C9	14.19^{ijk}	23.893^{a}	12.713^{no}	14.38^{hi}	10.85^{rst}	20.503^{c}	16.088^{a}	1.513	2.928
C10	12.983^{mn}	16.463^{g}	9.987^{uvw}	12.503^{nop}	8.67^{x}	14.763^{h}	12.562^{cde}	0.893	0.543
Means	12.647^{b}	17.438^{a}	9.882^{cd}	11.4^{bc}	8.457^{d}	13.677^{b}			

bi: Regression coefficient, S^2di: Deviation from regression

Table 7. *Means cultivars, environments and C X E interaction of total root dry weight (g) performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	S^2 di
C1	18.743^{s}	21.443^{i}	17.323^{x}	20.62^{l}	17.01^{yz}	18.687^{s}	18.971^{d}	0.945	0.004
C2	17.703^{w}	20.67^{l}	16.313^{BC}	19.567^{op}	16.263^{C}	17.74^{vw}	18.043^{f}	0.947	-0.001
C3	16.83^{yzA}	19.807^{n}	15.353^{D}	18.803^{s}	15.197^{DE}	16.873^{yzA}	17.144^{g}	0.990	-0.003
C4	16.83^{yzA}	19.607^{o}	15.287^{DE}	18.773^{s}	15.097^{E}	16.807^{zA}	17.067^{g}	0.975	0.005
C5	19.533^{op}	22.443^{g}	18.023^{tu}	21.44^{i}	17.867^{uvw}	19.377^{pq}	19.781^{c}	0.984	-0.003
C6	20.8^{l}	23.577^{c}	19.223^{qr}	22.677^{ef}	19.033^{r}	20.777^{l}	21.014^{b}	0.976	0.004
C7	19.577^{op}	22.553^{fg}	18.033^{tu}	21.49^{i}	17.943^{tuv}	19.453^{op}	19.842^{c}	0.994	-0.003
C8	17.993^{tu}	21.21^{jk}	16.783^{A}	20.07^{m}	16.507^{B}	18.103^{t}	18.444^{e}	0.992	0.003
C9	22.94^{d}	27.03^{a}	21.397^{ij}	24.917^{b}	21.11^{k}	22.783^{de}	23.363^{a}	1.198	0.092
C10	18.8^{s}	21.743^{h}	17.343^{x}	20.777^{l}	17.033^{y}	18.777^{s}	19.079^{d}	0.999	-0.001
Means	18.975^{c}	22.009^{a}	17.508^{d}	20.914^{b}	17.306^{d}	18.938^{c}			

bi: Regression coefficient, S^2di: Deviation from regression

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Soil surface wetting area (cm^2)

Table 8 shows the soil surface wetting area across six environments for ten maize cultivars. The highest overall mean was recorded in C2 (445.46 cm^2), followed closely by C10 (445.76 cm^2) and C6 (445.07 cm^2), indicating relatively superior soil moisture distribution, while the lowest mean was observed in C8 (437.33 cm^2). Cultivar C2, with bi = 1.005, was closest to the ideal stability (IS), while C1, with S^2di values closest to zero, exhibited the most consistent and linear response across environments. Ogola et al. (2013) concluded that when soil reaches field capacity, plants absorb water most efficiently, but as the soil dries below approximately halfway between field capacity and the wilting point, transpiration becomes increasingly limited. No significant differences were observed in soil surface wetting area among cultivars, consistent with the findings of Lawal et al. (2022). However, irrigation levels significantly affected the wetting area across environments, with 2 L irrigation (E1, E3, E5) reducing soil surface wetting area by about 35% compared with 4 L irrigation (E2, E4, E6). Similarly, sowing date comparisons revealed reductions of 28% between SD1 and SD3, 19% between SD1 and SD2, and 8% between SD2 and SD3.

Table 8. *Means cultivars, environments and C X E interaction of soil surface wetting area (cm^2) performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	$S^2{}_{di}$
C1	404.716^{k}	611.399^{c}	373.258^{mn}	476.592^{g}	361.932^{opqr}	436.0^{hi}	443.98^{a}	0.980	-1.191
C2	404.239^{k}	614.638^{abc}	370.976^{mno}	485.176^{fg}	361.483^{pqr}	436.252^{hi}	445.46^{a}	1.005	-17.409
C3	398.085^{kl}	610.518^{c}	368.485^{mnopq}	479.942^{g}	363.053^{opqr}	440.683^{h}	443.46^{a}	0.991	5.552
C4	398.795^{kl}	595.734^{d}	374.982^{m}	478.666^{g}	358.563^{r}	416.83^{j}	437.26^{a}	0.936	14.703
C5	405.903^{k}	618.992^{abc}	369.84^{mnop}	491.678^{ef}	364.403^{nopqr}	436.756^{hi}	447.93^{a}	1.023	-16.070
C6	392.915^{l}	621.281^{ab}	363.96^{opqr}	494.028^{e}	361.257^{pqr}	436.965^{hi}	445.07^{a}	1.062	9.861
C7	401.399^{kl}	623.16^{a}	370.085^{mnop}	478.136^{g}	359.462^{qr}	434.046^{hi}	444.38^{a}	1.040	1.424
C8	396.952^{kl}	594.28^{d}	373.716^{m}	484.367^{fg}	360.805^{pqr}	413.841^{j}	437.33^{a}	0.937	43.275
C9	398.566^{kl}	614.31^{bc}	369.841^{mnop}	480.512^{g}	364.183^{nopqr}	428.595^{i}	442.67^{a}	1.004	-13.794
C10	402.915^{k}	616.105^{abc}	367.344^{mnopqr}	490.401^{ef}	362.602^{opqr}	435.212^{hi}	445.76^{a}	1.021	-13.860
Means	400.449^{d}	612.042^{a}	370.249^{e}	483.95^{b}	361.774^{e}	431.518^{c}			

bi: Regression coefficient, S^2di: Deviation from regression

Soil moisture depth

Table 9 shows that soil moisture depth (SMD) did not differ significantly among cultivars, with means ranging narrowly from 31.69 to 31.79 cm. The highest value occurred in E6, while the lowest was in E3, reflecting strong environmental rather than genotypic effects. All cultivars had regression coefficients (bi) close to 1, indicating average responsiveness, and very low S^2di values, confirming stable performance across environments. Irrigation levels, however, significantly influenced soil moisture depth, with 2 L irrigation (E1, E3, E5) reducing SMD by about 51% compared with 4 L irrigation (E2, E4, E6). In contrast, sowing dates showed only minimal reductions, with differences of about 1% between SD1 and SD3 and between SD1 and SD2, indicating that sowing time had little impact on soil moisture storage. The relative consistency in mean soil moisture values across sowing dates likely reflects the uniform soil texture, structure, and water-holding capacity of the experimental field, which reduced variability in moisture

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retention among plots. These results are in line with Ogola et al. (2013), who reported that genotype can influence soil water depletion patterns at a depth of 30 cm, with certain cultivars extracting more water than others despite uniform field conditions.

Table 9. *Means cultivars, environments and C X E interaction of soil moisture depth (cm) performance. Stability parameters of different models of 10 maize hybrid cultivars at six different environments*

	E1	E2	E3	E4	E5	E6	Means	(bi)	$S^2{}_{di}$
C1	25.317^{hij}	38.237^{abcd}	25.223^{jk}	38.08^{d}	25.153^{jk}	38.14^{bcd}	31.69^{a}	1.001	0.002
C2	25.257^{ijk}	38.217^{abcd}	25.2^{jk}	38.103^{cd}	25.2^{jk}	38.157^{abcd}	31.69^{a}	1.003	0.006
C3	25.43^{fghi}	38.26^{abcd}	25.183^{jk}	38.14^{bcd}	25.12^{jk}	38.14^{bcd}	31.71^{a}	1.003	-0.003
C4	25.283^{hijk}	38.187^{abcd}	25.16^{jk}	38.127^{bcd}	25.183^{jk}	38.157^{abcd}	31.68^{a}	1.003	0.002
C5	25.577^{fg}	38.233^{abcd}	25.21^{jk}	38.197^{abcd}	25.29^{hijk}	38.137^{bcd}	31.77^{a}	0.994	-0.001
C6	25.417^{ghi}	38.293^{abc}	25.193^{jk}	38.253^{abcd}	25.123^{jk}	38.163^{abcd}	31.74^{a}	1.007	-0.002
C7	25.463^{fgh}	38.347^{a}	25.27^{ijk}	38.187^{abcd}	25.17^{jk}	38.153^{abcd}	31.77^{a}	1.002	-0.001
C8	25.76^{e}	38.307^{ab}	25.183^{jk}	38.12^{bcd}	25.103^{k}	38.12^{bcd}	31.77^{a}	0.995	0.018
C9	25.607^{ef}	38.183^{abcd}	25.13^{jk}	38.193^{abcd}	25.137^{jk}	38.113^{bcd}	31.73^{a}	0.998	0.004
C10	25.46^{fgh}	38.077^{d}	25.21^{jk}	38.173^{abcd}	25.19^{jk}	38.1^{cd}	31.70^{a}	0.994	0.001
Means	25.457^{b}	38.234^{a}	25.196^{c}	38.157^{a}	25.167^{c}	38.138^{a}			

bi: Regression coefficient, S^2di: Deviation from regression

Figure 8 shows Water use efficiency (WUE, kg/ha mm^{-1}) was determined according to Howell (2001) and it was varied notably among environments (E1–E6), reflecting the combined influence of sowing date, irrigation level, and rainfall.

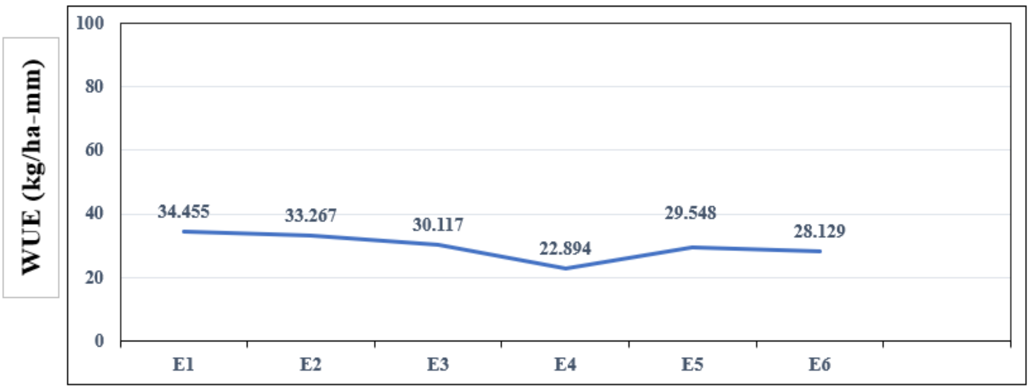

Figure 8. *Water use efficiency of 10 hybrid cultivars of maize that tested in six environments (different sowing dates, irrigation levels and considering rainfall contribution) in Bazian location, Kurdistan region-Iraq, growing season 2024*

The highest WUE was achieved in E1 (34.46) followed closely by E2 (33.27), indicating that early sowing (March 10) favored efficient use of the available water regardless of irrigation level. WUE declined in later sowings, with the lowest value in E4 (22.89), where delayed planting combined with higher irrigation and rainfall reduced efficiency. Intermediate efficiencies were observed in E3 (30.12), E5 (29.55), and E6 (28.13). These results highlight that early sowing dates maximize water productivity, while delayed sowing decreases efficiency even when more water (irrigation + rainfall) is supplied,

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likely this improvement can be attributed to the longer effective growing period, greater thermal time accumulation, and better synchrony between crop water demand and available soil moisture, including seasonal rainfall. When maize was sown later (SD2 and SD3), WUE consistently declined despite higher irrigation, reflecting shortened growth duration, reduced kernel set, and increased evaporative losses under warmer late-season conditions.

Conclusion

The study evaluated of ten spring maize hybrids under three sowing dates and two irrigation levels in Bazian revealed highly significant genotype (G), environment (E), and G × E interactions for key agronomic traits, including ear number, kernel number, 300-kernel weight, kernel yield, and total root dry weight. Early sowing combined with higher irrigation consistently produced superior performance and stability particularly for hybrid C9, which exhibited the highest mean kernel yield (16.09 t ha^{-1}), strong responsiveness (b_i = 1.513), and acceptable stability (S^2d_i = 2.928) across environments. These findings underscore the agronomic advantage of synchronizing sowing time with spring rainfall and optimizing drip irrigation to enhance yield and resource-use efficiency in water-limited Mediterranean-type climates. Early sowing of spring maize exploits residual soil moisture and spring rainfall to cut supplemental irrigation, conserving scarce water resources in this drought decade. This strategy sustains maize yields while enhancing water-use efficiency in water-limited Mediterranean-type climates. Early sowing improved maize WUE by aligning crop growth with cooler conditions and longer duration, while delayed sowing reduced efficiency despite higher water inputs.

Author contributions. Shokhan Mahmood Sleman (PhD student; this paper is part of my dissertation) conceived and designed the study, conducted the experiments, collected and analyzed the data, and drafted the manuscript. Dr. Kamil and Dr. Fawzy are my supervisors; provided supervision and guidance throughout the project, assisted with data analysis and interpretation, and critically revised the manuscript for important intellectual content.

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