Thesis of a doctoral (PhD) dissertation

EVALUATION OF FOLIAR FERTILIZATION ON MAIZE GROWTH, YIELD, GRAIN QUALITY AND QUANTITY UNDER IRRIGATED AND NON-IRRIGATED CONDITIONS

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1. INTRODUCTION

Maize (*Zea mays L.*), known as corn ranks among the oldest cereal crops with a significant contribution to the livelihood of humankind. The crop's origin can be traced to Southern Mexico approximately 9,000 years ago. Teosinte a well-known wild ancestor from which maize was domesticated through plant selection, breeding and cultivation (Awika, 2011). Maize formed a major part of pre-Columbian civilizations due it's widespread to America which later found its way to Europe, Asia and Africa through the Columbian exchange during the 15th and 16th centuries (Kennett et al., 2020). Due to favourable weather and agro-climatic conditions across the different agro-ecological regions, the crop easily adapted thus high cultivation and production. Since then to date, maize ranks among the most important cereals produced globally as a staple crop for both subsistence and industrial reasons.

FAO, (2017) estimated that the total global population will be 9.7 billion people by the year 2050, a call for increased nutritious food production. The recent cereal production statistics of 2024 recorded 2,853 million tonnes, major contributor to world food security (Laskowski et al., 2019), the three major cereals include wheat, rice, and maize (FAO, 2024). To meet the high food requirement of the growing population, maize production as a major cereal should be enhanced (Poole et al., 2021). The versatility of maize crop makes it a primary staple food for human consumption across all continents however it also contributes to sustainability of the livestock and animal industry since it's a major animal feed, the industrial and biofuel sectors also benefit tremendously from maize crop as primary production raw material (Grote et al., 2021). Maize differs from other cereals due to its high growth and yield potential, quality thus a valuable economic crop globally. Maize being a highly adaptive crop to different weather conditions, agro-ecological regions and cropping systems justifies its global significance.

The global maize cultivation and production is estimated at approximately over 200 million hectares and 1.2 billion metric tonnes annually respectively (García-Lara et al., 2019). The four major cereals include maize (1,151.36 tonnes), wheat (783.8 tonnes), rice (502.98 tonnes) and barley (150.48 tonnes). Global statistics distribute the regional maize production share as America (49.6%), Asia (32%), Europe (10.9%), Africa (7.4%) and Oceania (0.1%) (Figure 1) while the five biggest maize producers as United States, China, Brazil, Argentina, and India (FAO, 2023) thus contributing tremendously to the world's food basket, food and feed markets as well as international grain trade (Horváth et al., 2021). Europe contributes almost 7.4%% to the global maize production, purposely for both grain and silage. Prior to year 2022, highest maize producers of Europe were France, Romania, Hungary, Italy, and Ukraine. However, challenges of climatic variability affect agriculture in general and maize production (Ocwa et al., 2023). To furnish above needs, optimum maize production is paramount to the economy and livelihood of Hungary (Figure 1). Maintenance of high maize grain yield and other cereals needs fertile arable land and sustainable agronomic practices such as fertilization (Nagy, 2012), water supplementation and irrigation (Széles et al., 2012), favourable agro-climatic conditions (Illés et al., 2022).

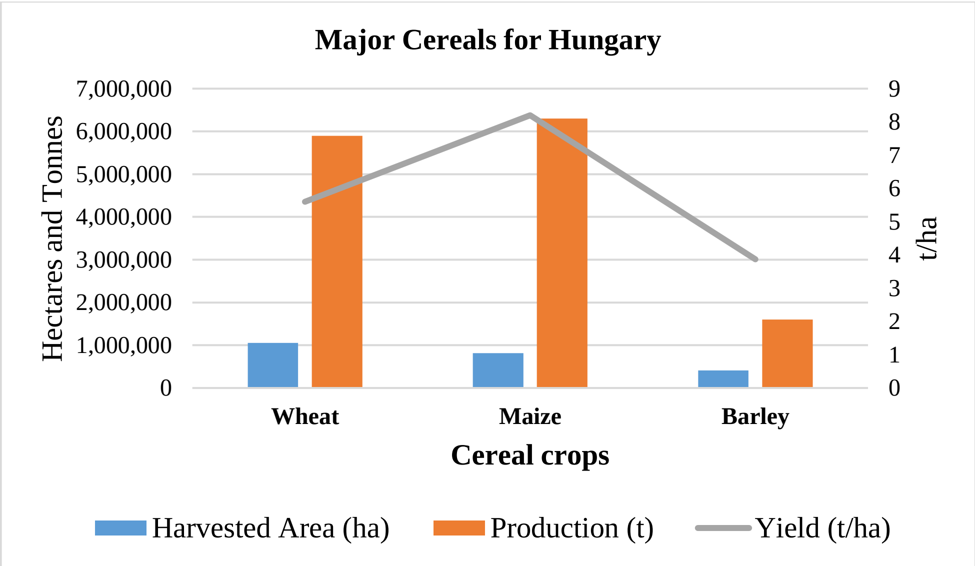

Figure 1 Major Cereal Production Statistics for Hungary by year 2023 (Source: HCSO, 2024)

Industrial development of foliar fertilisers in Hungary has taken center stage to counter soil nutrient and moisture deficiencies. Assessment of such foliar fertilisers, their efficiency and effectiveness address the knowledge and production gap between research and farmers as the final consumers. The hypothesis of our study is that efficient application of precision drip irrigation and foliar micronutrients (fertilisers) has no significant effect on physiological growth, yield and yield components, and corn grain quality. The study objectives are:

a) Determine the effect of precision drip irrigation and foliar fertilisation on physiological growth traits of maize.

b) Assess the yield and yield components of maize under foliar fertilisation and precision drip irrigation.

c) Evaluate the grain quality response to foliar fertilisation and precision drip irrigation.

d) Correlation analysis between physiological growth traits, yield components and overall grain yield.

2. MATERIALS AND METHODS

2.1 Experimental research site

The study conducted at Látókép Experimental Station of Plant Production, Farm and Regional Research Institute of Debrecen, Institutes for Agricultural Research and Educational Farm, University of Debrecen located 15 km from Debrecen, Eastern Hungary (47°56′N, 21°45′E, 111 m). The three years of study 2023-2025 recorded fluctuating temperature and precipitation data.

2.2 Experimental study design and treatments

The design of the experiment was a randomized split-plot field design replicated thrice (3) during the three growing seasons (2023-2025). 14th June 2023, 06th June 2024 and 6th June 2025 respectively installation of drip irrigation lines on the surface of the soil near maize plants was done in every row supplying water at 3 Liters per hour. The irrigation system was managed by the nearby meteorological station controlled by the Hydrawise app. Drip irrigation systems were removed on 22nd September 2023, 16th September 2024 and 26th September 2025 respectively. Foliar fertiliser treatment composition and application rates followed the manufacturer's recommendations as shown below. Foliar application was done when plant leaves were well-developed to absorb nutrients. Foliar application of nutrients was done on 3rd June 2023, 29th May 2024, and 4th June 2025 at V6 stage when maize plants had fully developed leaves that can absorb the nutrients easily.

This study was performed to evaluate performance of three maize hybrids under foliar fertilization in three replications for three years (2023–2025) under irrigated conditions. Maize hybrid studied included FAO420, FAO430 and FAO490. Foliar fertilizer treatment was composed of four different products consisting of different nutrients (Table 1), application was done using a Kertitox FSZM 800, made by FarmGep company in Debrecen with a capacity of 800 liters and 18 m spacing width. Precision drip irrigation lines were laid at surface near the plant rows supplying water at 3 L hr^{-1} intensity under control of the hydrawise app, managed by a meteorological station at the experimental site.

2.3 Sowing and management practices

Sowing was done during 20th April 2023, 11th April 2024, and 23rd April 2025 respectively using the Gaspardo MTR 4 pneumatic precision seed drill made in Campodarsego, Italy. One maize seed per hole was the sowing rate at a sowing depth of 5 cm spaced at 76.2 x 18.2 cm. Therefore, each hectare accommodated a total of 84.100 plants as total plant density.

Fertigation was done on 10th July 2023, Megasol orange (25 kg fertiliser) NPK 3-5-40 (0,875 kg N, 1,25 kg P_2O_5, 10 kg K_2O); 20th June 2024, Megasol orange (50 kg fertiliser) NPK 3-5-40 (1,75 kg N, 2,5 kg P_2O_5, 20 kg K_2O) and 31st July 2025, Megasol orange (50 kg fertiliser) NPK 3-5-40 (1,75 kg N, 2,5 kg P_2O_5, 20 kg K_2O).

Table 1: Foliar fertiliser treatment composition

Product 1: 3l/ha	Composition	g/L
	Nitrogen	132
	P_2O_5	1.2
	K_2O	36
	Ca	0.96
	Co	0.0324
	Cu	1.56
	Mg	4.8
	Zn	1.8
	Fe	3.6
	Mn	2.4
	Mo	0.12
	B	2.4
	S	4.8
Product 2: 1l/ha	Composition	g/L
	Zn^{2+}	120
	SO_4^{2-}	59.4
Product 3: 1l/ha	Composition	g/L
	$S_2O_3^{2-}$	330
	SO_3	825
	NH_4^+	165
Product 4: 1l/ha	Composition	g/L
	Mg^{2+}	64.9
	MgO	106.4
	NH_4^+	73.8

2.4 Data collection

Field measurements on physiological growth traits were done at 12-leaf stage (V12), tasselling stage (VT), and silking-physiological maturity (R1-R6). Yield, yield components and grain quality data were collected after harvesting of grains from the field.

2.5 Assessment of Physiological growth, yield and yield traits

The physiological growth parameters studied were Soil Plant Analysis Development (SPAD), plant height, Normalised Difference Vegetation Index (NDVI), Leaf Area Index (LAI). Measurements were conducted from the field using the SPAD-502 Plus Chlorophyll Meter (Konica Minolta Inc., Tokyo, Japan) to measure the relative chlorophyll from a third last well-developed leaf and the opposite leaf at both vegetative and reproductive stages respectively. A meter ruler was used to measure plant height in centimetres (cm). GreenSeeker hand-held crop sensor (Trimble Inc., Sunnyvale, CA, USA) was employed to measure NDVI. SS1 SunScan Canopy Analysis System (Delta-T Devices Ltd., Cambridge, UK) was used for measuring LAI. Fifteen (15) measurements were collected from the field and average was calculated.

Yield and yield parameters included yield per hectare, cob weight (g), row number, cob number, cob length (cm), cob diameter (mm), grain number per row, number of grains per cob, 1000 seed weight, and seed weight (g). Harvesting from the field was conducted when the black layer appeared in the grains on 28th September 2023, 19th September 2024 and 10th October 2025 respectively. A random selection of ten (10) maize ears from each replication was done. A Haldrup lt-35 laboratory thresher (HALDRUP GmbH, Ilshofen, Germany) was used to thresh the selected maize ears. An electronic weighing balance was employed to measure cob weight (g), a VSC-201 Vibrating Seed Counter (PLC Tuning Ltd, Hungary) was used to measure the weight of 1000 seeds (g) and the number of seeds per cob, a meter ruler was used to measure the cob length (cm), digital Vanier calliper for measuring the cob diameter (mm), manual counting and recording was done to determine the rows per cob, seed weight per cob and weight of 1000-seeds were determined. Grain yield (GY) in t ha^{-1} was calculated based on a moisture content of 14.5%.

2.6 Grain quality assessment

Determination of grain quality parameters including oil content, protein content, moisture content, and starch content was done using Perten DA7250 NIR infrared grain analyser. The used grain analyser obtained data at the capacity of 30 spectra at an interval of 5 nm. The study samples were assessed at 570-1100 nm range.

2.7 Statistical data analysis

Data analysis utilized the ANOVA method employing Genstat 64-bit Release 18.2 software. Mean differences among treatments were evaluated using Tukey test at 5% probability level. Pearson correlations were employed to examine the relationship between physiological parameters, yield traits and grain yield. OriginPro Graphing and Analysis Software (version 2024) was used to prepare figures for the study.

3. RESULTS AND DISCUSSION

3.1 Physiological and growth response to foliar fertilisation and precision drip irrigation

Plant height

In 2023 growing season, average plant height didn't differ significantly among hybrids FAO420 (333.5cm), FAO430 (329.8cm) and FAO490 (333.3cm). Precision drip irrigation significantly influenced plant height ($P<0.001$). The precision drip irrigation x foliar fertilisation interaction positively influenced ($P = 0.047$) plant height. In 2024 growing season, plant height was significantly different ($P = 0.036$) among hybrids FAO420 (302.7 cm), FAO430 (322.5 cm), FAO490 (330.4 cm). Foliar fertilisation had no significant effect on plant height. Precision drip irrigation significant improved plant height ($P < 0.001$). Irrigation x foliar fertilisation interaction had no significant effect on plant height. During 2025 growing season, plant height significantly improved due to foliar fertilisation ($P<.001$) and the hybrid x foliar fertilisation interaction. Foliar fertilisation treatment improved plant height of maize plants (342.2) compared to control (301.9) (Figure 2). Our findings corroborate with recent findings that maximum irrigation optimised plant height (Nawaz et al., (2024). Nik-Khah et al. (2024) reported that foliar micronutrient application ($MnSO_4$, $FeSO_4$, and $ZnSO_4$) significantly improved plant height.

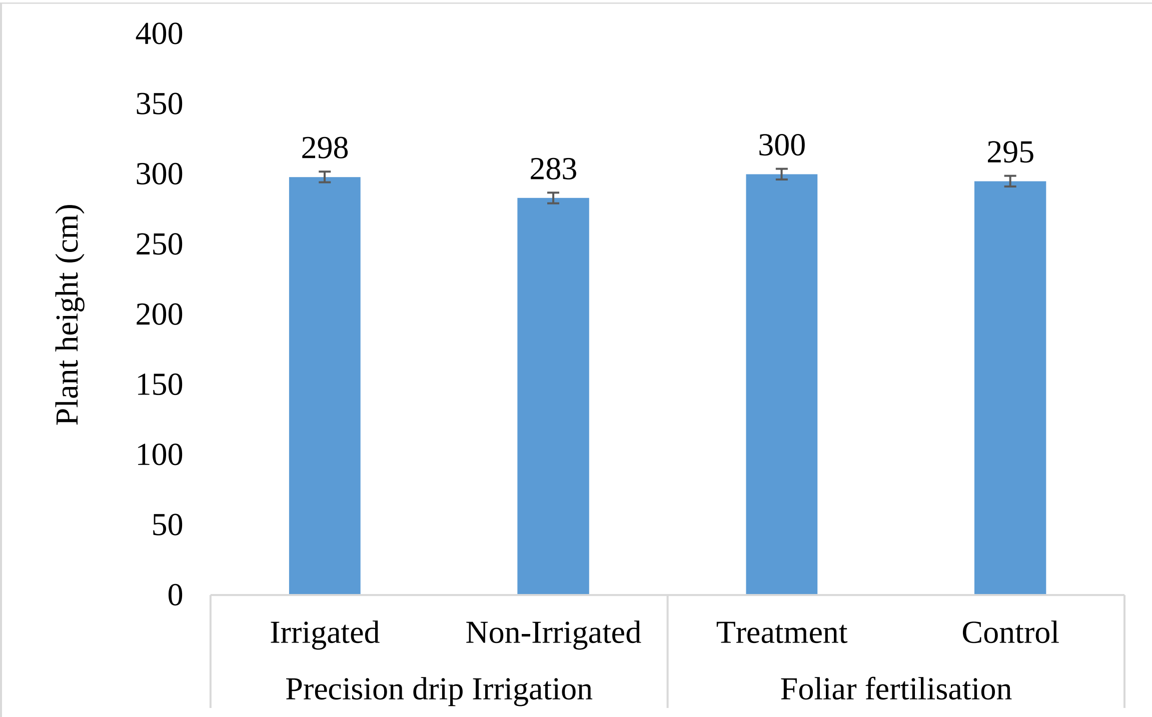

Figure 2 showing the overall effect of precision drip irrigation and foliar fertilisation on plant height,

Leaf Area Index (LAI)

In 2023 experimental season, Leaf Area Index (LAI) was significantly different ($P < 0.001$) among hybrids FAO420 (4.35), FAO430 (6.22), and FAO490 (6.59) respectively. Foliar fertilisation had no significant effect on LAI. Precision drip irrigation significantly influenced ($P = 0.025$) LAI. The interaction between hybrid × irrigation had a positive significant effect ($P = 0.002$). In 2024 growing season, the mean LAI values of hybrids were significant different ($P < 0.001$). Foliar fertilisation didn't have a significant effect on LAI. Precision drip irrigation had a significant effect ($P = 0.025$) on LAI. During the 2025 experimental year, Leaf Area Index significantly improved due to irrigation (P=0.0017), foliar fertilisation (P<.001), hybrid x irrigation (P= 0.001), irrigation x foliar fertilisation (P=0.002) while hybrid, hybrid x irrigation, hybrid x irrigation x foliar fertilisation interaction was non-significant (Figure 3). Recent studies have noted the positive impact of irrigation on leaf area index (Nawaz et al., 2024), which agrees with our findings that precision irrigation significantly improved LAI across different years.

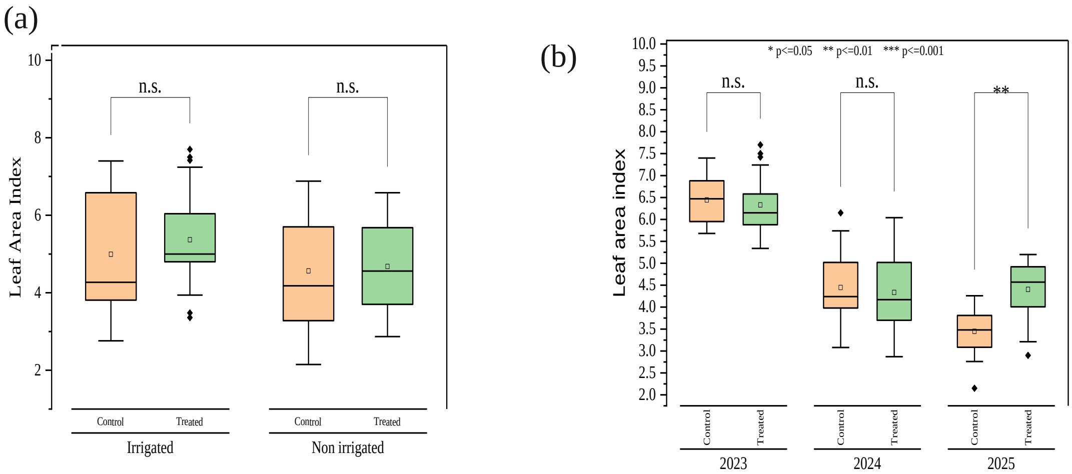

Figure 3 Leaf Area Index (LAI); (a) interaction effect of precision drip irrigation x foliar fertilisation and (b) effect of foliar fertilisation on LAI; ns shows non-significance difference and ** indicate significant differences by Tukey test at p<0.05 during the 2023, 2024 and 2025 growing seasons.

Normalised Difference Vegetation Index (NDVI)

In 2023 experimental season, NDVI didn't differ significantly among hybrids FAO490 (0.689), FAO420 (0.708) and FAO430 (0.746). Precision drip irrigation had a positive effect ($P = 0.020$) on NDVI. Foliar fertilisation treatment slightly improved ($P = 0.055$) NDVI. In 2024 experimental season, statistically significant hybrid differences ($P = 0.027$) on NDVI were noted as FAO420 (0.69), FAO430 (0.750), and FAO490 (0.763). Foliar treatment recorded a higher NDVI value (0.746) than control (0.723). Precision drip irrigation was non-significant (P > 0.25). During the 2025 experimental season, the mean NDVI values of hybrids were FAO490 (0.7368), FAO430 (0.7137) and FAO420 (0.7037). Foliar fertilisation positively influenced (P<.001) NDVI. Precision drip irrigation conditions improved NDVI (0.7327) compared to non-irrigated conditions (0.7034) (Figure 4). Our findings agree with Tamás et al. (2023) that irrigation positively influenced NDVI. Similarly, Balaout et al. (2022) reported that foliar fertiliser application improved NDVI by 8 % and 25 % respectively.

(a)

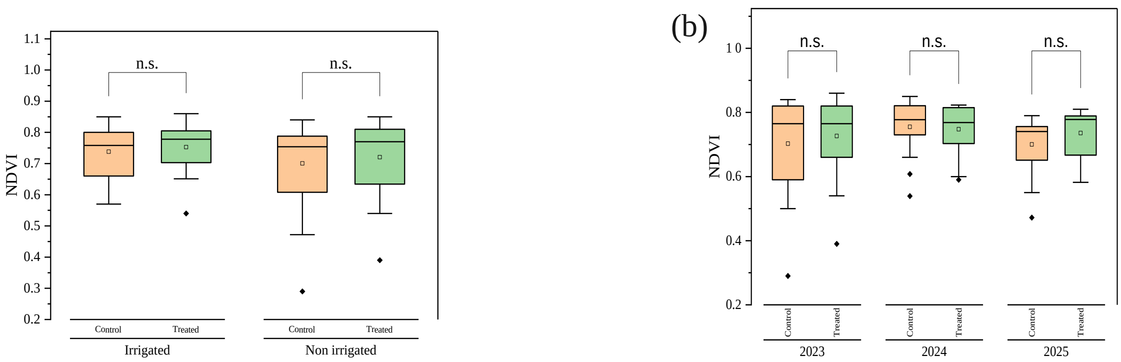

Figure 4 NDVI; (a) interaction effect of precision drip irrigation x foliar fertilisation and (b) effect of foliar fertilisation on NDVI; ns indicates non-significant differences by Tukey test at p<0.05 during the 2023, 2024 and 2025 growing seasons.

Soil Plant Analysis Development (SPAD)

In 2023 experimental season, SPAD didn't differ significantly among hybrids, FAO430 (56.55), FAO420 (51.3) and FAO490 (50.63). Precision drip irrigation significantly (P = 0.002) influenced SPAD. Foliar fertilisation had no significant effect on SPAD. In 2024 experimental season, the SPAD value of different hybrids was FAO430 (58.56), FAO420 (52.5) and FAO490 (51.63). Precision drip irrigation had a positive effect (P = 0.002) on SPAD. Higher SPAD values (56.82) under irrigated plots compared to non-irrigated plots (51.79), thus a 9.71% difference. Though foliar fertilisation had no significant effect, a 3.62% difference was recorded between treated (55.81) and control (53.86). Irrigation that had a strong statistical significance, foliar fertilisation with negligible effect, all the interactions had no significant effect on SPAD values in 2024. During the 2025 growing season, hybrid, irrigation and all interaction effects were non-significant. The mean hybrid SPAD values were FAO430 (49.05), FAO490 (47.90) and FAO420 (47.32). Foliar fertilisation significantly (P<.001) improved SPAD, foliar treatment had a high SPAD value (52.43) than control (43.75). Precision drip irrigation conditions improved SPAD (49.36) compared to non-irrigated conditions (46.82). The irrigation x foliar fertilisation interaction showed that foliar fertilisation treatment improved SPAD (54.14 and 50.72) compared to control (44.58 and 42.93) under irrigated and non-irrigated conditions respectively (Figure 5). Notably, foliar fertilisation had a 12 % and 4 % SPAD improvement at 12-leaf and silking growth stages (Balaout et al., 2022).

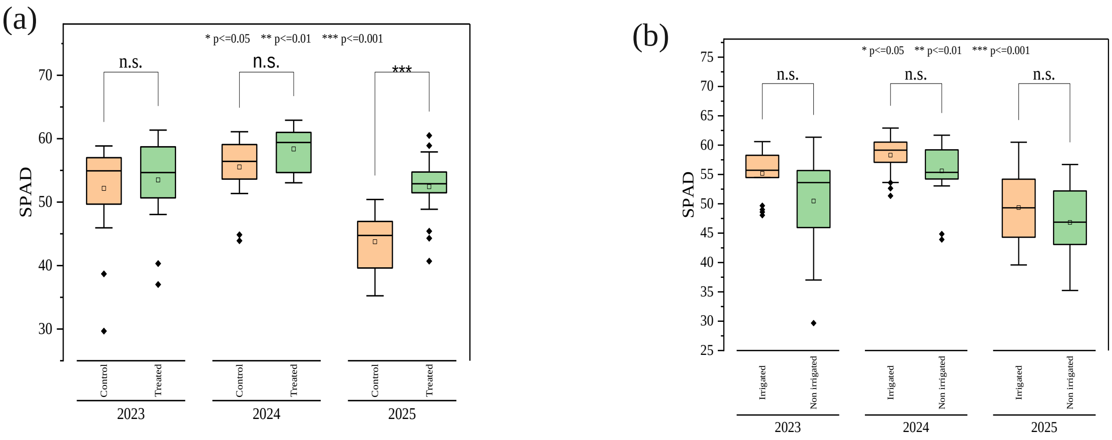

Figure 5 SPAD; (a) effect of foliar fertilisation and (b) effect of precision drip irrigation on SPAD; ns indicates non-significant differences and *** indicates significant difference by Tukey test at $p<0.05$ during the 2023, 2024 and 2025 growing seasons.

3.2 Yield components of maize hybrids under foliar fertilisation and precision drip irrigation

Cob diameter

In 2023 growing season, cob diameter (mm) of hybrids varied significantly (p = 0.003), ranging from FAO430 (52.80 mm), FAO420 (47.93 mm) and FAO490 (49.63 mm) respectively. Precision drip irrigation (p = 0.031), precision drip irrigation x foliar fertilisation interaction (p < 0.001) significantly influenced cob diameter. Foliar fertilisation had no significant effect on cob diameter. In the 2024 growing season, cob diameter among hybrids was significant (p = 0.030), FAO430 (51.12 mm), FAO490 (49.51 mm) and FAO420 (46.45 mm) respectively. Foliar fertilisation, precision drip irrigation and all their interactions had no statistical significance on cob diameter. During the 2025 growing season, cob diameter was positively influenced (P<0.001) by hybrid, precision drip irrigation and foliar fertilisation. The interaction between precision drip irrigation and foliar fertilisation had no significant effect on cob diameter. FAO430 recorded the largest cob diameter (49.54 mm), 10.8% and 1.5% larger than FAO420 and FAO490 respectively (Figure 6). A study by Yadav et al. (2024) correlated with our findings indicating that significant differences on cob diameter among different maize varieties was noted with cob diameter values varying between 13.85 cm to 15.56 cm, respectively.

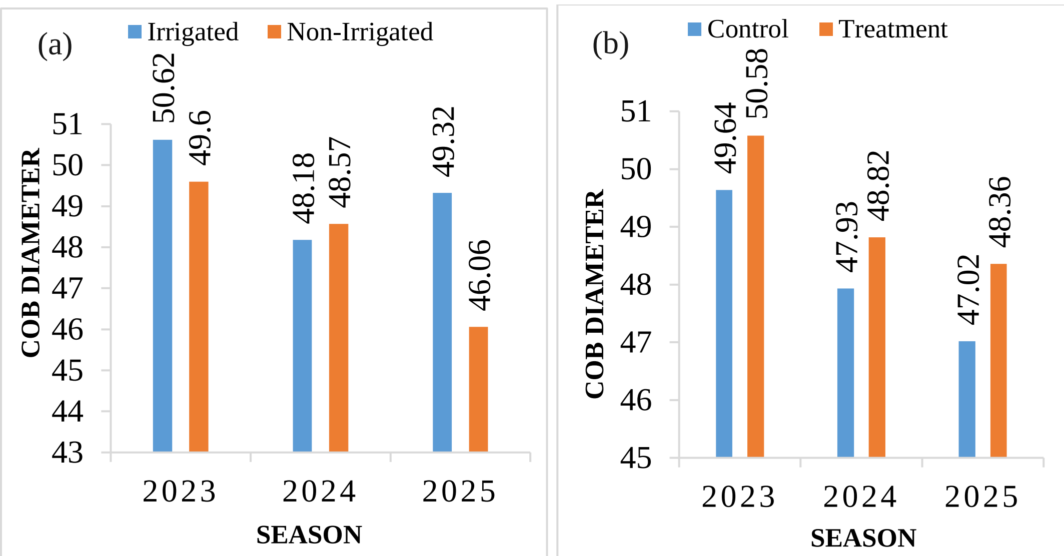

Figure 6 Cob diameter; (a) effect of precision drip irrigation and (b) effect of foliar fertilisation on cob diameter during the 2023, 2024 and 2025 growing seasons.

Cob length

The mean cob length of hybrids was FAO420 (18.83 cm), FAO430 (18.37 cm) and FAO490 (19.17 cm) respectively during the 2023 growing season. Precision drip irrigation significantly influenced ($p < 0.001$) cob length. Foliar fertilisation and all interactions showed no statistical significance on cob length. In 2024 growing season, cob length of hybrids was significantly different ($p = 0.007$), FAO490 (19.17 cm), FAO420 (17.33 cm) and FAO430 (16.63 cm) respectively. During the 2025 growing season, both precision drip irrigation and precision drip irrigation x foliar fertilisation positively influenced ($P<0.001$) on cob length. Hybrid, and foliar fertilisation had no significant effect on cob length. Precision drip irrigation increased cob length by 5.1% with cob length of 18.4 cm and 17.5 cm for irrigated and non-irrigated conditions respectively (Figure 7). Chinasho et al. (2023) showed that blended fertilizer application produced higher performance in terms of cob length.

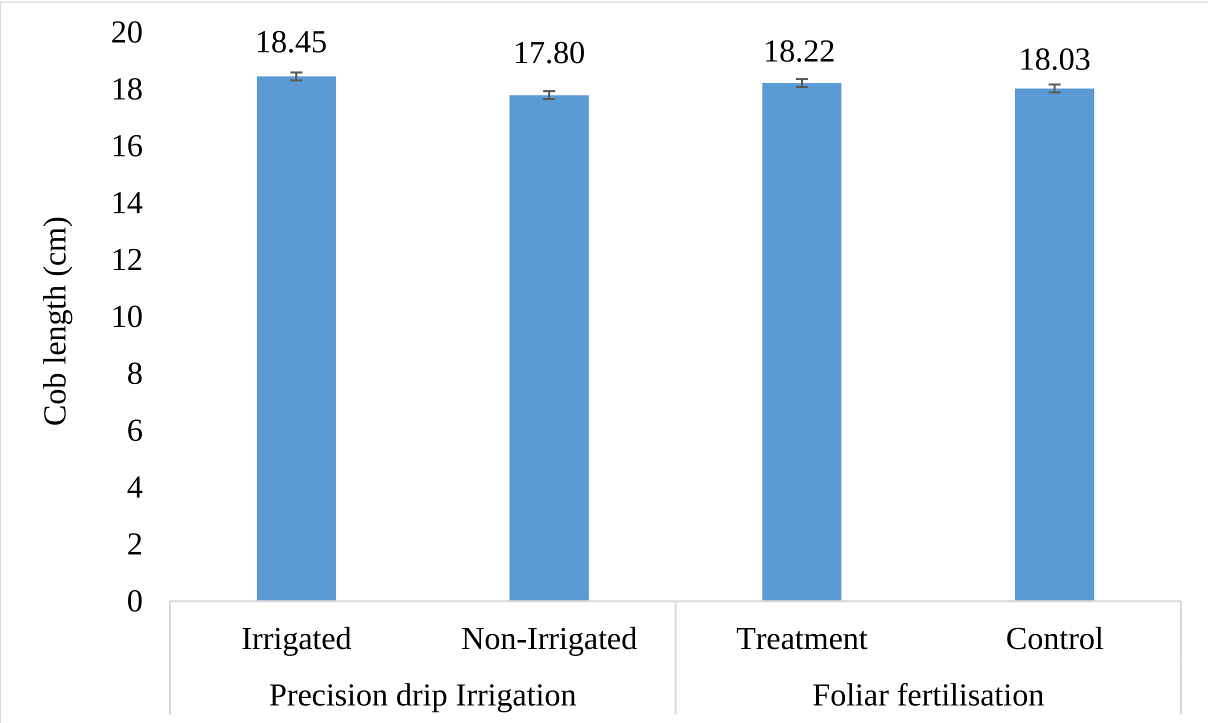

Figure 7 Cob length (cm); showing the overall effect of (a) precision drip irrigation and foliar fertilisation;

Cob weight

In 2023 growing season, cob weight of hybrids was FAO430 (315.2 g), FAO420 (226.7 g) and FAO490 (274.0 g). Foliar fertilisation × precision drip irrigation interaction had a positive significant effect ($p = 0.019$) on cob weight. There were no significant effects noted for foliar fertilisation, irrigation, foliar fertilisation × irrigation interaction, hybrid × foliar fertilisation ×

irrigation interaction on cob weight. In 2024 growing season, cob weight of hybrids was significantly different ($p = 0.009$), FAO490 (262.1 g), FAO430 (235 g) and FAO420 (203.8 g) respectively. Foliar fertilisation × precision drip irrigation interaction had a significant ($p = 0.036$) effect on cob weight. During the 2025 growing season, cob weight was positively influenced ($P < 0.001$) precision drip irrigation and foliar fertilisation. Precision drip irrigation increased cob weight by 34.7% with a weight of 254.0 g and 188.5 g for irrigated and non-irrigated conditions respectively (Figure 8). Similarly, precision drip irrigation positively improved cob weight in 2022 and 2023 seasons with weight values of 222.19 g and 304.6 g compared to 57.3 and 261.9 g under non-irrigated conditions (Ocwa et al., (2024).

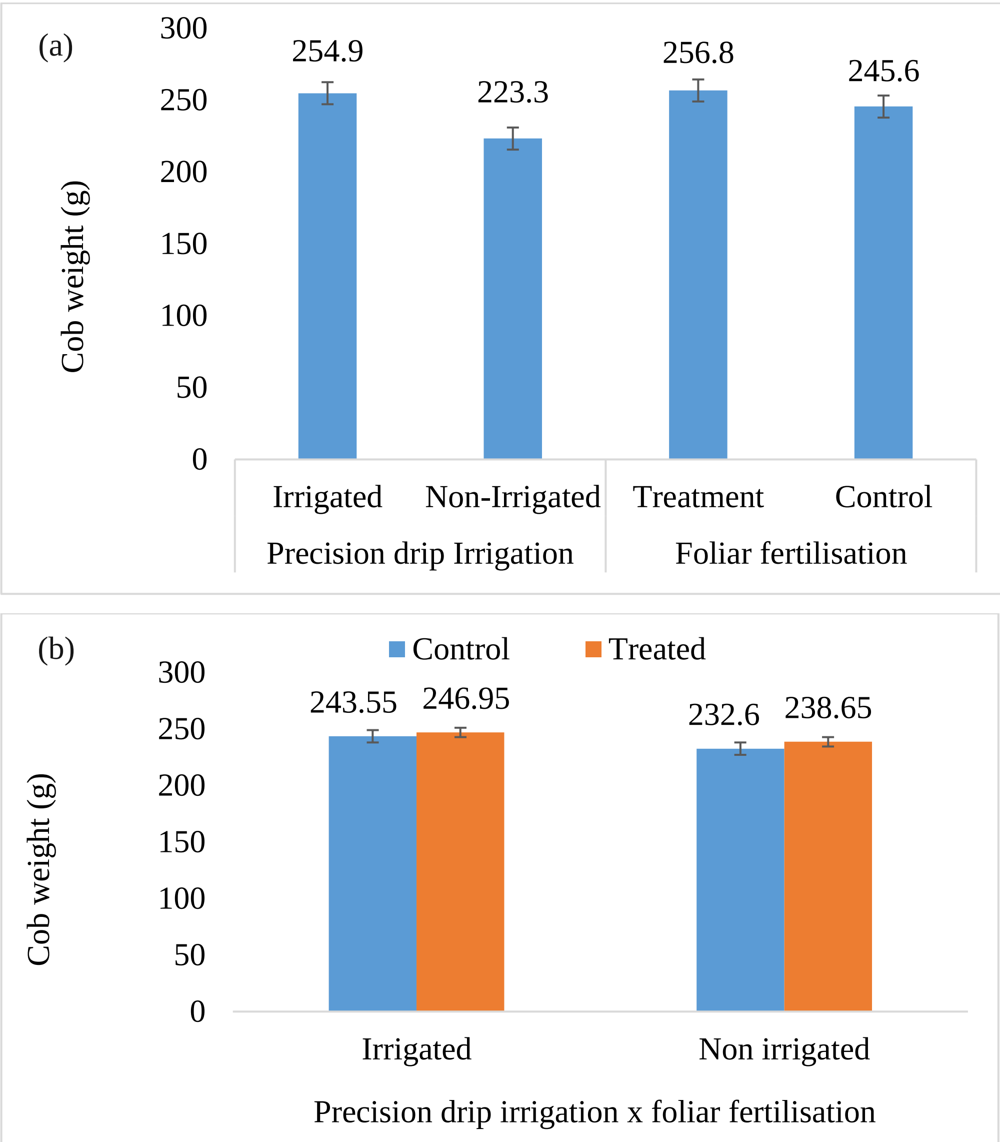

Figure 8 showing the (a) overall effect of precision drip irrigation and foliar fertilisation; interaction effect between precision drip irrigation and foliar fertilisation on cob weight.

1000-seed grain weight

In 2023 growing season, a significant effect ($p < 0.001$) of hybrid on 1000-seed weight showed that FAO430 (536.0 g), FAO490 (477.8 g), and FAO420 (433.6 g). Foliar fertilisation had no positive effect on 1000-seed weight. Treatment produced slightly higher average seed weight (497.8 g) than the control (481.6 g), thus a 3.4% difference. Precision drip irrigation had a significant effect ($p < 0.001$) on 1000-seed weight. In 2024 growing season, FAO490 had the highest mean 1000-grain weight (477.4 g), compared to FAO430 (459.7 g) and Hybrid 420 (428.4 g). Hybrid x foliar fertilisation x precision drip irrigation ($p < 0.001$) had a significant effect on the 1000-grain weight while foliar fertilisation and irrigation effects were non-significant ($p > 0.05$) the 1000-grain weight. During the 2025 growing season, 1000-seed weight significantly improved ($P<0.001$) due to precision drip irrigation and foliar fertilisation. The 1000-seed weight increased by 15.9% and 18.7% due to precision drip irrigation and foliar fertilisation respectively (Figure 9). Ocwa et al. (2024) during the 2022 and 2023 growing seasons noted that 1000-seed weight of corn significantly improved due to application of precision drip irrigation with weight values of 363.3 and 534.7 g compared to 268.3 and 505.2 g under non-irrigated conditions.

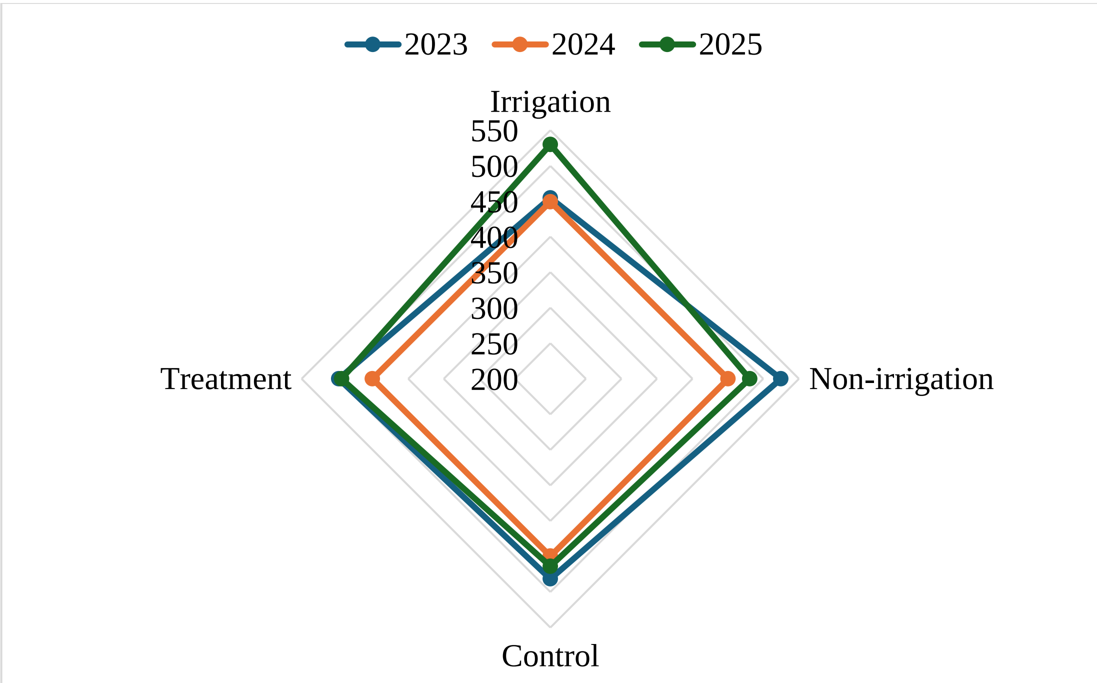

Figure 9 Radar chart of 1000 grain weight of kernels for control and treatment under precision drip irrigation and non-irrigated (NI) conditions during the three growing seasons (2023-2025).

Grain weight

In 2023 growing season, FAO430 hybrid had the highest mean grain weight (240.1 g), compared to FAO490 (226.4 g), and FAO420 (216.3 g). Foliar fertilisation effect was non-significant. Precision drip irrigation had a significant effect ($p = 0.012$) on grain weight. In 2024 growing season, grain weight of hybrids was significantly different ($p = 0.009$), FAO490 had the highest grain weight (235.1 g), compared to FAO430 (208.2 g) and FAO420 (173.8 g). Foliar fertilisation, precision drip irrigation, and all the interaction effects were non-significant ($p > 0.05$). During the 2025 growing season, grain weight was positively influenced ($P<0.001$) by both precision drip irrigation and foliar fertilisation. The seed weight increased by 36.3% and 10.6% due to precision drip irrigation and foliar fertilisation respectively (Figure 10). Deshpande et al. (2017) studied the application of foliar fertilisers at critical growth stages which improved grain weight.

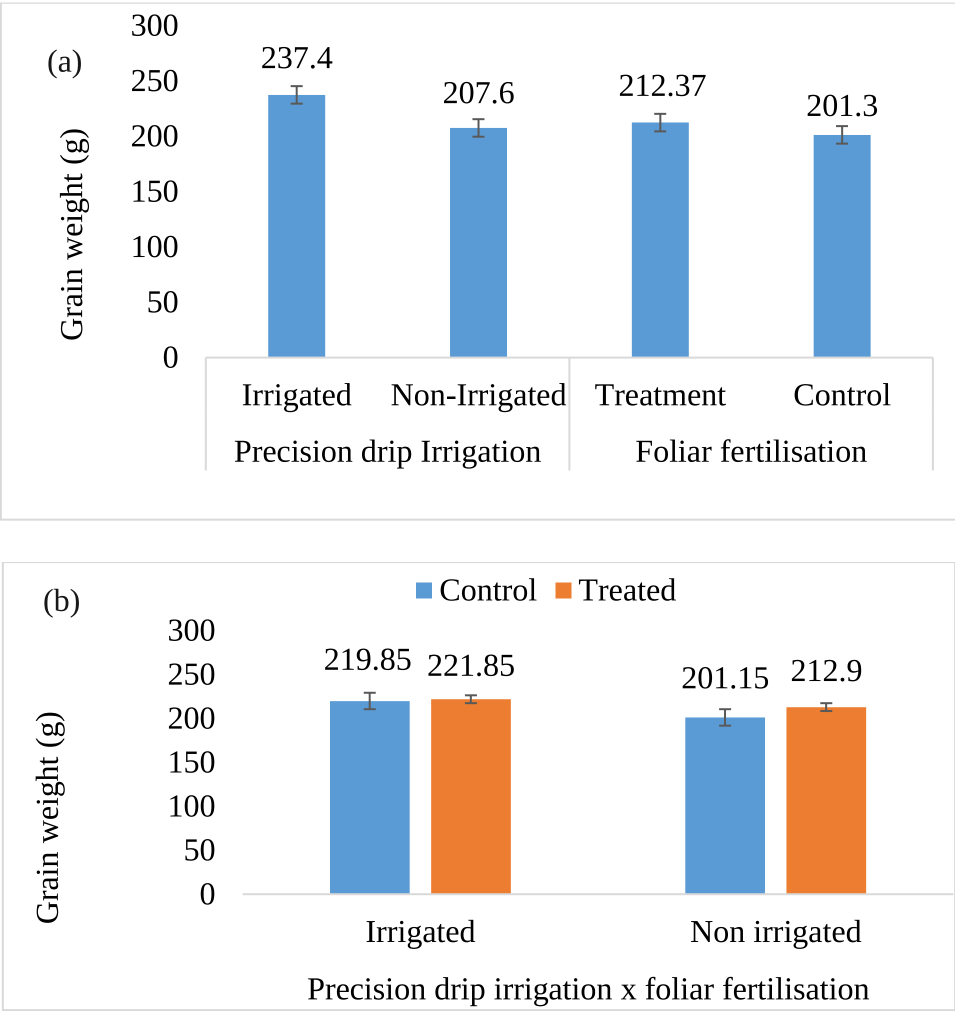

Figure 10 Grain weight (g); showing effect of (a) precision drip irrigation and foliar fertilisation; (b) the interaction effect of precision drip irrigation x foliar fertilisation on grain weight.

3.3 Grain quality response to foliar fertilisation and precision drip irrigation

Moisture content (%)

In 2023 growing season, Moisture content was significant among hybrids FAO430 (16.084%), FAO490 (15.390%) and FAO420 (14.170%). Hybrid x foliar fertilisation interaction was significant (P<.001). Precision drip irrigation, foliar fertilisation and all other interactions were non-significant. Foliar fertilisation treatment had a 15.226% moisture content slightly higher than the control (15.204%). Precision drip irrigation had a lower moisture content (15.106%) than non-irrigated conditions (15.323%). In the 2024 growing season, precision drip irrigation, hybrid x precision drip irrigation and precision drip irrigation x foliar fertilisation significantly influenced (P<.001) grain moisture content. Moisture content of hybrids was FAO490 (12.763%), FAO430 (12.753%), FAO420 (11.863%) respectively. During the 2025 growing season, hybrid and irrigation showed significant differences (P < 0.001) while foliar fertilisation was non-significant. FAO490 had the highest moisture content (16.79%) compared to FAO430 (15.76%) and FAO420 (14.61%). Also, Tejada et al. (2018) noted that biostimulant foliar fertilisation optimized maize quality.

Oil content (%)

In 2023 growing season, oil content of grain was significantly affected by the interaction between hybrid and foliar fertilisation (P=0.007). Hybrid, precision drip irrigation, foliar fertilisation and all other interactions were non-significant. Oil content of hybrids was FAO430 (3.638%), FAO490 (3.667%) and FAO420 (3.692%) respectively. In the 2024 growing season, grain oil content was marginally influenced foliar fertilisation. Precision drip irrigation and all interactions were non-significant. Oil content of hybrids was significantly different FAO420 (3.576%), FAO430 (3.468%), and FAO490 (3.300%) respectively. During the 2025 growing season, hybrid showed significant differences (P < 0.001) while irrigation and foliar fertilisation were non-significant. FAO430 had the highest oil content (3.50%) compared to FAO420 (3.40%) and FAO490 (3.04%). Foliar fertiliser application at critical phenological stages has proved effective towards improvement of maize grain quality boosting carbohydrate content, oil content, fibre content, protein content, kernel size, mineral content and grain weight (Deshpande et al., 2017).

Protein content

In 2023 growing season, protein content of grain was significantly affected by the hybrid (P=0.003). precision drip irrigation, foliar fertilisation and all interactions had no significant effect on protein%. FAO430 had the highest protein content (6.992%) compared to FAO420

(6.211%), and FAO490 (5.706%). In 2024 growing season, protein content of grain was significantly affected by the hybrid (P=0.024), precision drip irrigation x foliar fertilisation (P=0.017) and hybrid x precision drip irrigation x foliar fertilisation (P=0.009). FAO430 had the highest protein content (7.7173%) compared to FAO420 (6.853%), and FAO490 (6.200%). Precision drip irrigation was non-significant. Foliar fertilisation treatment had slightly high protein content (6.361%) than control (6.245%). During the 2025 growing season, hybrid and foliar fertilisation showed significant differences ($P < 0.001$) while irrigation was non-significant. FAO430 had the highest protein content (6.16%) compared to FAO420 (5.77%) and FAO490 (5.59%). Foliar Ortho Silicic Acid (OSA) application improved dry matter content (11.3%), protein content (1.3%), and ash content (3.3%) however detergent fibre content (2.0%) and percent acid detergent fibre content (2.7%) decreased (Biswal et al., 2024).

Starch content

Grain starch content was significantly different among hybrids (P=0.001), hybrid x foliar fertilisation interaction had a significant effect (P=0.006) on starch%. Precision drip irrigation, foliar fertilisation and all other interactions had no significant effect on starch%. FAO420 had the highest starch content (65.012%) compared to FAO490 (63.737%), and FAO430 (62.973%). Starch content was high under non-irrigated conditions (64.044%) compared to irrigated conditions (63.771%). In 2024 growing season, grain starch content was significantly different among hybrids (P=0.041). Precision drip irrigation, foliar fertilisation and all other interactions had no significant effect on starch%. FAO420 had the highest starch content (64.558%) compared to FAO490 (63.767%), and FAO430 (62.767%). Precision drip irrigation was non-significant. During the 2025 growing season, hybrids had different starch concentration, similarly foliar fertilisation and precision drip irrigation significantly influenced ($P < 0.001$) starch content. FAO420 had the highest starch concentration (62.98%) compared to FAO430 (61.25%) and FAO490 (60.75%). There was a slight increase in starch content due to the foliar fertiliser application (Rácz et al., 2021).

3.4 Yield response to foliar fertiliser application and precision drip irrigation

During the 2023 growing season, hybrid and foliar fertilisation positively influenced ($P < 0.001$) grain yield while irrigation had no significant effect. Hybrid yield performance was FAO420 (14.01 t ha^{-1}), FAO430 (17.79 t ha^{-1}) and FAO490 (17.46 t ha^{-1}). Precision drip irrigation had no significant influence on grain yield. Foliar fertilisation positively influenced grain yield. Foliar treatment had a 4.2% yield increased grain yield (16.76 t ha^{-1}) than control (16.08 tha^{-1}). During the 2024 growing season, hybrid, foliar fertilisation, and irrigation positively influenced ($P < 0.001$) grain yield. Hybrid yield performance was FAO420 (16.47 t ha^{-1}), FAO430 (16.34 t ha^{-1}) and FAO490 (18.03 t ha^{-1}). Contrary to 2023 growing season, precision drip irrigation had a strong positive significant influence ($P < 0.001$) on grain yield. Foliar fertilisation treatment significantly improved grain yield by 5.7%, grain yield for treatment was (17.42 t ha^{-1}) than control (16.48 t ha^{-1}). During the 2025 growing season, hybrid, foliar fertilisation, irrigation and hybrid x irrigation interaction positively influenced ($P<0.001$) grain yield. Hybrid yield performance was FAO420 (15.99 t ha^{-1}), FAO430 (18.64 t ha^{-1}) and FAO490 (19.98 t ha^{-1}). Precision drip irrigation had a strong positive significant influence ($P < 0.001$) on grain yield. Foliar fertilisation treatment significantly improved grain yield by 18.7%, grain yield for treatment was (19.76 tha^{-1}) than control (16.65 t ha^{-1}) (Figure 11). Recent studies support our study findings as foliar fertiliser application increased maize yield. Zinc (ZnI) foliar application increased maize yield from 892 to 2519 kg ha^{-1} (Rehman et al., 2021).

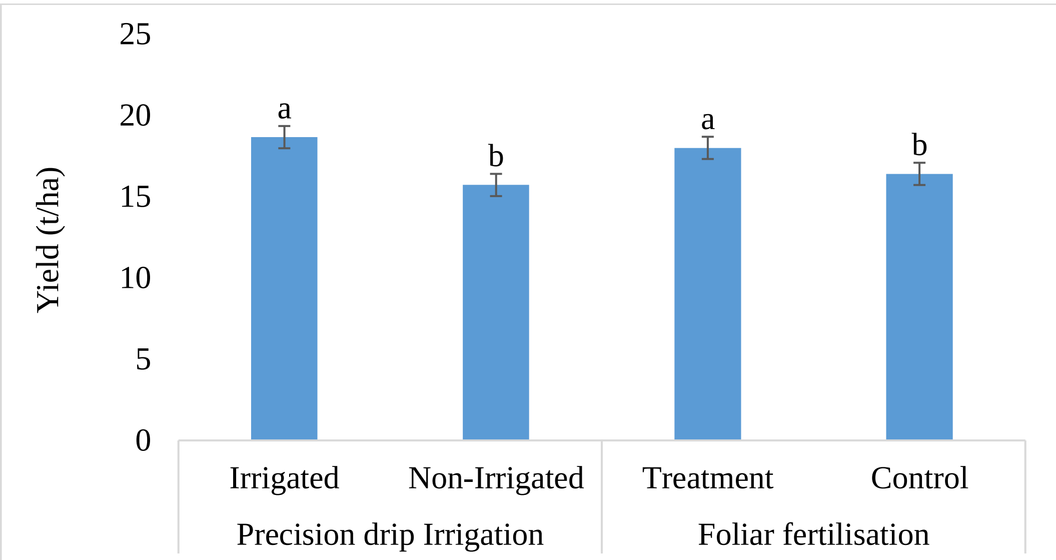

Figure 11 yield (t ha^{-1}); showing grain yield as affected by precision drip irrigation and foliar fertilisation across the experimental period.

3.5 Correlation analysis between physiological growth, yield parameters and overall grain yield

Correlation between physiological growth parameters and overall grain yield

The analysis of correlation between different physiological parameters namely plant height, NDVI, SPAD and leaf area index established significant relationship with overall grain yield across the experimental period. Plant height, SPAD, and leaf area index have exhibited a positive linear correlation with grain yield ($P < 0.001$), while NDVI showed a weak linear relationship with yield ($P = 0.285$). The correlation coefficient (r) of plant height, SPAD, leaf area index NDVI have been noted as (0.5636, 0.514, 0.552, and 0.183) respectively (Table 2). Our results agreed with recent studies. Plant height had a significant correlation with increased grain yield as reported by (Dhakal et al., (2017).

Correlation between yield components and overall grain yield

Correlation analysis established significant positive linear relationship between all yield components studied and overall grain yield (t ha^{-1}). Cob length (cm), cob diameter (mm), cob weight (g), the number of grains per cob, seed weight (g), seeds per row, and Thousand seed weight had a significant effect ($P < 0.001$) on overall grain yield with correlation coefficient (r) of 0.464, 0.644, 0.713, 0.649, 0.743, 0.444, and 0.471 respectively (Table 3). The results agree with recent studies, grain yield was substantially positively associated with ear diameter, thousand kernel weight, days to physiological maturity, tassel length, ear length, and ear weight (Pariyar et al., 2018).

Table 2: Correlation (relationship) between physiological growth parameters and grain yield

Trait	**Correlation Coefficient (r)**	**P-value**	**Simple description**
Plant Height (cm)	0.5636	<0.001	Positive linear relationship
NDVI	0.1832	0.2848	Weak linear relationship
SPAD	0.5141	0.0013	Positive linear relationship
Leaf Area Index	0.5523	<0.001	Positive linear relationship

Table 3: Correlation (relationship) between yield parameters and grain yield

Trait	**Correlation Coefficient (r)**	**P-value**	**Description**
Cob length	0.4639	0.0044	Moderate linear relationship
Cob diameter	0.6438	<0.001	Positive linear relationship
Cob weight	0.7130	<0.001	Positive linear relationship
Seed weight	0.7428	<0.001	Positive linear relationship
Number of grains per cob	0.6489	<0.001	Positive linear relationship
Number of seeds per row	0.4435	0.0067	Moderate linear relationship
Thousand seed weight	0.4714	0.0037	Moderate linear relationship

4. NEW SCIENTIFIC RESULTS

The following are the new scientific results of this study.

1. Physiological growth parameters improved across the three-year period due to foliar fertilisation and irrigation. Plant height, LAI, NDVI and SPAD improved by 3.5%, 5.9%, 3% and 5% under irrigated conditions compared to 7.3%, 10.9%, 9% and 10% under non-irrigated conditions. Foliar fertilisation increased NDVI and SPAD by 2–5% and 2–20% compared to the control. The interaction between precision drip irrigation and foliar fertilisation improved plant height and LAI by 10–14% and 20–23% compared to control.
2. FAO490 consistently performed better than FAO420 and FAO430. Plant height, LAI and NDVI of FAO490 improved by 4-42% under irrigated conditions while NDVI and plant height improved by 6–8% under non-irrigated conditions due to foliar fertilisation across 2023, 2024 and 2025. FAO490 recorded 9-27% and 10-25% higher yield compared to FAO420 and FAO430 across 2023, 2024 and 2025. Precision drip irrigation x foliar fertilisation recorded a 20% higher yield for FAO430 and FAO490 hybrids than under non-irrigated conditions.
3. Foliar fertilisation effectively improved grain weight, 1000 grain weight of kernels, number of rows per cob, cob weight, cob length and cob diameter improved by 3-33%, 3-21%, 1-5%, 3-12%, 1-9% and 1-4% respectively compared to control. Precision drip irrigation improved cob diameter, cob weight and 1000 grain weight of kernels by 7.1%, 34.7% and 17.0% respectively.
4. Foliar fertilisation and precision drip irrigation significantly increased ($p<0.001$) grain yield. Foliar fertilisation enhanced grain by 4.2%, 5.7%, 18.7% compared to control, while precision drip irrigation increased yield by 1.4%, 38.3%, and 18.9% compared to non-irrigated conditions across 2023, 2024 and 2025 growing seasons. Precision drip irrigation × foliar fertilisation interaction increased grain yield by 4.7%, 3.7%, 13.0% under irrigated conditions and 3.8%, 8.5%, 25.9% under non-irrigated conditions respectively. Overall, foliar fertilisation and precision drip irrigation increased grain yield by 4–19% and 1–39% respectively compared to control.
5. Grain quality parameters were influenced by foliar fertilisation and precision drip irrigation. Foliar fertilisation consistently enhanced protein content, oil content, and starch content by 2–8%, 1–3%, and 1–2% compared to the control. Grain moisture content was higher by 3–14% under irrigation compared to non-irrigated conditions,

while moisture content was 1–3% slightly higher due to foliar fertilisation compared to control.

6. Correlation analysis revealed significant relationship between physiological growth, yield components and grain yield. Plant height, SPAD, and LAI, cob length, cob diameter, cob weight, the number of grains per cob, seed weight, seeds per row, and thousand seed weight exhibited a positive linear correlation coefficient (r) of 0.5636, 0.514, 0.552, 0.183, 0.464, 0.644, 0.713, 0.649, 0.743, 0.444, and 0.471 respectively with grain yield. Maize yield wasn't only controlled by physiological parameters but also sink strength and grain filling efficiency.

4. PRACTICAL UTILIZATION OF RESULTS

Precision drip irrigation and targeted foliar fertilisation together with proper hybrid selection offers a clear strategy to improve maize productivity, resource-use efficiency, and reduce effects of climatic stress.

1. The study findings offer vital insights to improve maize production systems for areas affected by adverse climate changes such as drought. Precision drip irrigation demonstrated consistent results thus enhancing and stabilising both growth and grain yield. Practically adopting precision drip irrigation ensures efficient and adequate timely water supply improving soil moisture needed at critical growth stages such as tasselling, silking, and grain filling. This targeted water supplementation maximised grain yield as well as reduced water losses through evaporation and deep percolation. This renders it suitable precision technology for semi-arid and drought areas.
2. Foliar fertilisation proved a cost-effective complementary precision management strategy alongside precision drip irrigation. The results showed that physiological traits and yield components improved due to foliar fertilisation, this enhanced nutrient-use efficiency of plants where root uptake might have been constrained. Practically farmers apply foliar fertilisation as both a corrective and supplemental management approach to correct any transient nutrient deficiencies observed at key phenological stages other than only relying solely on higher basal fertiliser rates.
3. The findings on genotype-specific responses identified act as a guiding tool for hybrid selection. Farmers can select hybrids for intensive production systems that consistently performed well under different conditions namely irrigated conditions and foliar fertilisation. Conversely, hybrids that performed well under non-irrigated conditions and control (no foliar fertilisation) should be targeted for production in resources and infrastructure constrained regions as this helps farmers match genetic potential of hybrids with available resources and management strategies.
4. Application as an in-season diagnostic tool to farmers, and agronomists. The strong correlations findings between physiological traits, yield components, and overall grain yield offers a practical way by which timely and effective measure of irrigation and foliar fertilisation effects can be monitored using crop growth status thus taking proper and timely management decisions to improve yields.

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Total IF of journals (all publications): 21,6
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