Article

Stimulating maize growth under different water regimes through foliar application of micronutrients

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Abstract: Drought and nutrient stress constrain maize growth, production and productivity. Precision agricultural tools such as foliar fertilisation and irrigation enhance maize growth through mitigation of stresses at different growth stages. The study conducted at Látókép Crop Production Experimental Site, University of Debrecen, Hungary during year 2023, assessed the physiological and growth performance of two maize hybrids exposed to foliar fertilisation under precision drip irrigation and non-irrigated conditions. Foliar fertilizers composed of; nitrogen (10 g/l), zinc (8 g/l), K2O (8.5 g/l), P2O5 (0.83 g/l), and S (8.93 g/l). Data on plant height, leaf area index (LAI), normalized difference vegetation index (NDVI), and relative chlorophyll content (SPAD) were collected at the V12, R1, R4, and R6 analysed using a T-test in Genstat software (12th edition). Results showed significant increases in all parameters at the V12, R1, and R4, but NDVI, LAI, and SPAD declined at R6 under both irrigation and non-irrigated conditions. Foliar fertilisation of the two maize hybrids under precision drip irrigation conditions showed that NDVI and plant height had a significant difference ($p < 0.05$) while no significance difference was noted for SPAD and leaf area index. The percentage LAI due to foliar fertilisation under irrigated conditions was 16.86% and 18.39% for FAO490 and FAO290 respectively however the effect was slightly higher for FAO290 than FAO490. FAO490 and FAO290 hybrids recorded a 23.45% and 10.05% foliar fertilisation effect respectively over control under non-irrigated conditions. FAO490 hybrid consistently performed better under irrigated conditions compared to FAO290 which performed better under non-irrigated conditions. FAO490 hybrid consistently performed better under irrigated conditions compared to FAO290 which performed better under non-irrigated conditions.

Keywords: Foliar fertilisation; Physiological Growth; Precision Drip Irrigation; Maize Hybrid; Water stress

1. Introduction

Cereals significantly address concerns of global food security [1], making them foundational components of diets in both developed and developing nations. World cereal production in 2022 increased by 8.3 million tonnes (0.3%), worldwide grain production represented; corn (1,151.36), wheat (783.8), rice (502.98), barley (150.48) [2]. Cereals namely wheat, rice, and maize, have a global impact serving as major staple food highly consumed by billions of people [3], as well as important animal feeds [4]. Cultivation of cereals has contributed to development of rural economies as well as shaping international markets through trade [5, 6]. Therefore, sustainable cultivation and innovation in cereal production enhance nutritional needs of a growing global population. Among the major cereals, maize, highly versatile and widely cultivated cereal [7], exerts a substantial global impact [8]. Furthermore, it contributes to global biofuel production boosting renewable energy industry [9]. However, challenges such as adverse weather extremes, water scarcity, drought, stress, soil infertility, pests and diseases underscore the need for sustainable maize farming practices to ensure food security and economic resilience on a global scale [10, 11]. Therefore, increasing the average yield, yield stability and quality of maize is of utmost importance.

Global maize production, limited by several multifaceted challenges impacting food security and economies [1]. Several abiotic and biotic stresses such as climate change-induced uncertainties [12], water scarcity, soil infertility, drought [13], socioeconomic factors, market dynamics, and evolving pest pressures pose significant threats. Climate change and soil fertility deterioration significantly contribute to decline in maize production [1, 13]. Drought stress impacts maize nutritional status [14], thus a need to provide balanced mineral nutrients [15, 16]. Different parts of the world including Europe have been hit by drought spells recently increasing temperature and reduced precipitation [17, 18], causing economic losses among farmers. Temperature is considered as primary factor that influences plant growth and development [19], determining potential maize productivity and quality [7, 20]. Temperature and heat accumulation affects maize phenological and growth stages, determining dry matter distribution and accumulation [19]. In Europe, Hungary has been mostly affected by climate change impacting agricultural production [21], with predictions of increased drought prevalence during closing years of the 21st century [17, 22].

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Research studies have documented the need for strong climate adaptation strategies to safeguard against serious drought impacts leading to food insecurity and economic losses [23, 24]. The presence of water deficits during various crop growth stages elicits different yield responses, contingent on crop sensitivity. Augmenting irrigation during critical growth stages enhances yield and water productivity [25]. Maize irrigation surpasses rainfed maize in water use efficiency [26]. Precision dripping irrigation enhances soil aeration and moisture [27]. Proper irrigation methods, such as drip systems, precisely deliver water where needed, ensuring timely supply and water application efficiencies vary such as surface irrigation (60-90%); sprinkler irrigation (65-90%); drip irrigation (75-90%) [28]. Therefore, uniform distribution of irrigation water in the field enhances water use efficiency because of precision irrigation delivery systems.

Depleted soil fertility hampers nutrient availability. Fertiliser use plays a central role in increasing maize yield [7, 29]. The degradation of Hungarian soil has significantly impacted maize production [30]. A recommended approach to bolster maize yields involves nutrient replenishment [31, 32]. The application of NPK fertiliser proves effective in enhancing maize yield, particularly during brief crop growth periods [33]. Advancements in fertiliser development enable precise control of nutrient supply to plants, curbing environmental pollution [34]. Foliar fertilisation is significant tool for the sustainable and productive management of crops [35, 36]. Foliar fertilisation is one of the precision practices to avert stress effect on crops since these abiotic and biotic stresses have a significant effect on crop growth and yield. Foliar fertiliser improves growth and yield by providing nutrients as well as ameliorating abiotic and biotic stresses. It's an effective way to improve chlorophyll content, photosynthetic rate, boost resistance to pests and diseases [37], decrease lipid peroxidation, and maintain homeostasis in crops like maize (*Zea mays* L.) [38], exposed to stress. This later improves yield and grain quality [38, 39, 40]. Ivanov et al. [41] reported an increase in quantum yield due to foliar application of ZnO. Zinc (Zn) played a crucial role in drought stress resistance through regulation modifying plant physiological processes [41]. Supplementing maize with nutrients like zinc improves crop yields [42], boron as micro-nutrient highly influences yield of maize at different locations [43]. The present study assessed the impact of foliar fertilisation on physiological growth of early maturing and late maturing maize hybrids under varying water availability conditions

2. Materials and Methods

Experimental site: The study was conducted at Látókép Crop Production Experimental Site, University of Debrecen, Hungary in the growing season of 2023. The soil type of the experimental station was high-quality calciferous chernozem soil.

Experimental materials: FAO490 (mid maturity group) and FAO290 (early maturity group) maize hybrids are the two main hybrids studied under this research. Foliar fertilizer treatments consisted of different nutrients such as: Nitrogen, K_2O, P_2O_5, Zn, S, Fe, MgO, Cu, Na, C, Co, B, Ca, essential vitamins and amino acids.

Soil sampling and sowing: Soil sampling was initially conducted before sowing; soil samples were collected from different parts of the field and laboratory analysis conducted for soil moisture testing. Sowing was done on 20th April 2023 at a plant population of 74.000 maize plants/ha.

Experimental design, treatments and irrigation management: The experimental design was a randomized split-plot field experiment. Surface drip irrigation was installed during the month of May 2023 preceding onset of drought and removed when the plants attained physiological maturity. Foliar fertilizers contain nitrogen (10 g/l), zinc (8 g/l), K_2O (8.5 g/l), P_2O_5 (0.83 g/l), and S (8.93 g/l). Foliar application was done once at 8th leaf stage when plant leaves had fully developed with enough leaf surface area to absorb nutrients. Other agronomic practices such as weed management and row cultivation were performed as recommended. Surface drip irrigation lines were laid on 14th June 2023 in every row near the plants at the intensity of 3 liters per hour controlled by hydrawise app, managed by nearby meteorological station and removed on 22nd September 2023.

Data collection stages: Physiological growth data was collected at different phenological stages namely, V12, R1, R4, and R6 stage.

Field data collection: After foliar fertilizer application, data collection started on both physiological parameters and progressed until harvest on 28th September 2023. Data was categorically collected on plant physiological parameters namely, plant height, leaf area index (LAI), normalized difference vegetation index (NDVI), relative chlorophyll content

(SPAD). Different equipment was used for data collection. Plant height (cm), was measured using a meter rule, NDVI using Greenseeker while LAI used a sun scan. Chlorophyll content was determined using SPAD chlorophyll meter in the third fully expanded leaf. Relative chlorophyll content values range (SPAD values) from 0–99 estimated from leaf transmittance coefficients at 650 nm and 940 nm [44].

Statistical analysis: Data was analyzed using T-test using Genstat software (12th edition). Figures and graphs were drawn using Minitab software (18th edition).

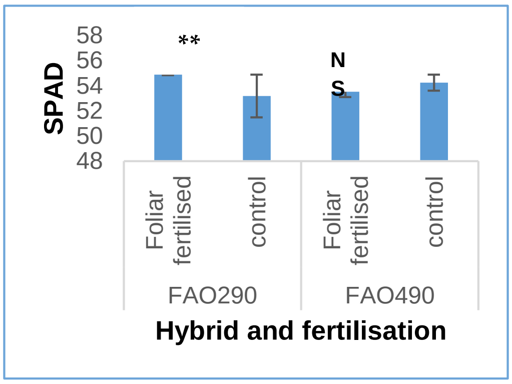
3. Results

Hybrid physiological and growth performance due to foliar nutrient application under irrigated conditions

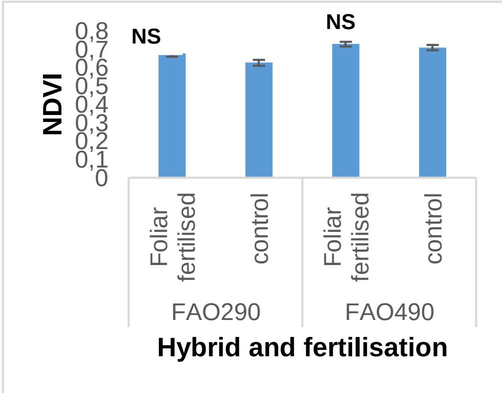
Foliar fertilisation of the two maize hybrids under precision drip irrigation conditions showed that NDVI and plant height had a significant difference ($p < 0.05$) while no significance difference was noted for SPAD and leaf area index. Comparison of foliar fertilisation effect on physiological growth of both hybrids on growth stages showed a 2.3% (SPAD), 10.12% (NDVI) and 11.3% (LAI) for FAO490 and 15.13% (SPAD), 0% (NDVI), 6.3% (LAI) for FAO290 at V12 stage. NDVI and LAI of both hybrids had no significant difference with control, however, an 8.3% and 12.3% SPAD value was recorded for FAO490 and FAO290 respectively at R1 growth stage. Plant height, NDVI and leaf area index of both hybrids had no significant difference with control, a 5.3% SPAD value for FAO290 at R4 stage under irrigated conditions. At R6 stage, both FAO490 and FAO290 had a 2.1% and 42.6% respectively attributed to foliar fertilisation under irrigated conditions, but NDVI and LAI had no significant difference for both hybrids. Therefore, foliar fertilisation effect differed for both hybrids at different growth stages.

Hybrid physiological performance due to foliar fertilisation under irrigation noted a 55.75 and 54.04 SPAD values for FAO290 and FAO490 due to foliar fertilisation respectively, compared to 53.17 and 54.22 SPAD values of FAO290 and FAO490 for control. FAO290 had a 4.74% foliar fertilisation effect compared to control. There was a significant difference for plant height for both hybrids. FAO290 had a significant difference ($p < 0.05$) of plant height compared to FAO490 however no significant difference recorded between foliar treatment and control for both hybrids. Plant height values of 329.1cm and 329.5cm for FAO490 compared to 348.3cm and 340.1cm of FAO290 for both treatment and control respectively (Figure 1). Both hybrids had a 5.7% and 3.19% between treatment and control. A significant difference ($p < 0.05$) for NDVI between both hybrids but there was no significant difference between treatment and control. FAO490 had 0.71 while FAO290 had 0.678 and 0.625 NDVI values for foliar treatment and control (Figure 1). The percentage NDVI difference of 4.54% and 8.14% due to foliar fertilisation for FAO490 and FAO290 respectively, almost double effect for FAO290 compared to FAO490. Both hybrids had no significant difference for leaf area index. FAO490 had 6.37 and 5.38 while 6.32 and 5.26 LAI values for FAO290 for foliar treatment and control (Figure 1). The percentage LAI due to foliar fertilisation was 16.86% and 18.39% for FAO490 and FAO290 respectively however the effect was slightly higher for FAO290 than FAO490. The experimental results above showed that foliar fertilisation slightly improved different physiological growth parameters compared to control. Both SPAD and plant height had no significant fertilisation effect for FAO490 while slightly higher values for all parameters were recorded for FAO290 compared to control. Therefore, FAO290 showed a slightly better physiological and growth performance than FAO490 due to foliar fertilisation under precision drip irrigation conditions.

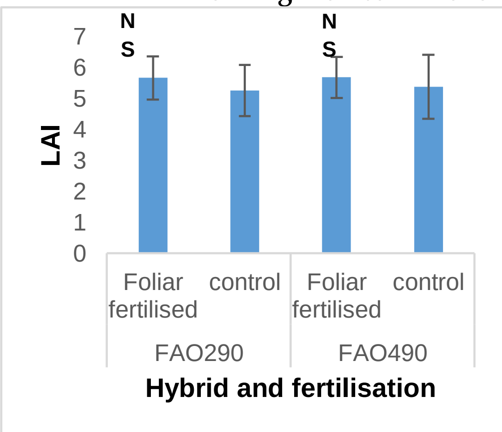
1. SPAD difference between FAO290 and FAO490 under irrigation conditions



2. NDVI difference between FAO290 and FAO490 under irrigation conditions



3. LAI difference between FAO290 and FAO490 under irrigation conditions



4. Plant Height difference between FAO290 and FAO490 under irrigation conditions

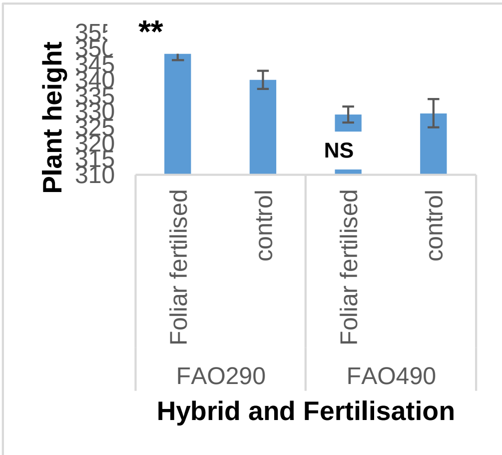


Figure 1; Represents hybrid physiological growth performance due to foliar nutrient application under precision irrigation conditions; * indicates significant difference at P=0.001; ** indicates significant at $P < 0.05$; NS shows non-significant difference.

Hybrid physiological and growth performance due to foliar nutrient application under non-irrigated conditions

SPAD showed a significant difference ($p < 0.05$) between FAO290 and FAO490, while Leaf Area Index (LAI), plant height and NDVI had no significant difference. At all growth stages, both hybrids showed no significance difference between treated and control. The SPAD values varied between the two hybrids, 53.4 (treated) and 52.03 (control) for FAO290, better than 48.2 (treated) and 45.83 (control) for FAO490 (Figure 2). The foliar fertilisation percentage difference of 5.04% and 2.60% for FAO490 and FAO290 respectively compared to control was recorded. Therefore, foliar fertilisation slightly improved SPAD values for both hybrids however FAO490 hybrid performed better than FAO290 under similar conditions. NDVI values did not have a significant difference for foliar treatment and control for both hybrids. The NDVI values were as follows; 0.68 (treated) and 0.66 (control) for FAO490 hybrid while 0.68 (treated) and 0.66 (control) for FAO290 (Figure 2). An implication that foliar fertilisation had no significant impact on NDVI values for both hybrids. There was a slight difference between leaf area index for both hybrids whereby FAO490 hybrid had better leaf area index than FAO290 under non-irrigated conditions. The leaf area index values were 6.34 (treatment) and 5.01 (control) for FAO490 hybrid compared to 5.54 (treated) and 5.01 (control) for FAO290 hybrid (Figure 2). Leaf Area Index values above indicate that a 13.02% difference for foliar treated FAO490 over treated FAO290, with no difference between control of both hybrids. Foliar fertilisation effect on leaf area index was evident for both hybrids compared to control. FAO490 and FAO290 hybrids recorded a 23.45% and 10.05% foliar fertilisation effect respectively over control. Plant height for both hybrids was not significantly influenced by foliar fertilisation. Plant height values of 323.8cm (treatment) and 319.2cm (control) for FAO490 compared to 324.6cm (treated) and 329.2cm (control) for FAO290 were recorded (Figure 2). Foliar fertilisation slightly improved plant height by a 1.43% difference for FAO490 hybrid while there was no observed foliar fertilisation effect in FAO290. Both hybrids showed improved physiological growth performance because of foliar fertilisation under non-irrigated conditions except FAO290 hybrid whose plant height (control) had a slight difference to treatment though not significant.

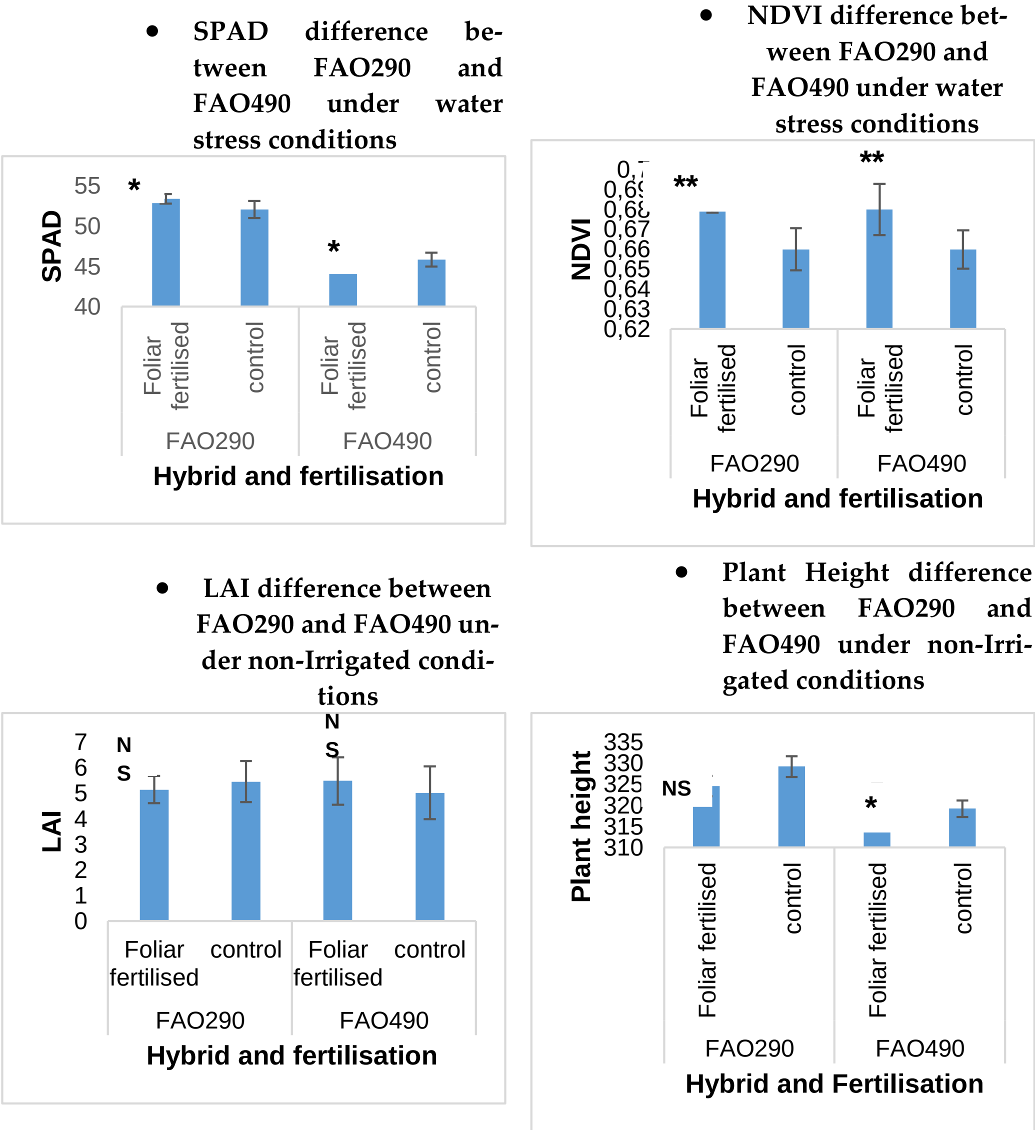


Figure 2; Represents hybrid physiological growth performance due to foliar nutrient application under water stress conditions; * indicates significant difference at P=0.001; ** indicates significant at $P < 0.05$; NS shows non-significant difference

Effect of irrigation on physiological and growth performance of hybrids

Foliar fertilisation under irrigated conditions showed that FAO490 hybrid recorded a significantly better leaf area index value of 7.36 compared to 6.8 under non-irrigated conditions. A reverse trend was recorded for FAO290 hybrid whereby 6.52 and 5.64 leaf area index values were recorded for non-irrigated and irrigated conditions respectively. The NDVI values recorded for both hybrids almost had the same trend as leaf area index, 0.75 and 0.66 NDVI values of irrigated and non-irrigated conditions respectively for FAO490 hybrid, while FAO290 hybrid under non-irrigated conditions recorded a 0.78 value slightly higher than 0.76 under irrigated conditions. SPAD values showed a significant difference between irrigated and non-irrigated conditions for both hybrids. FAO490 hybrid had a 12.4% SPAD difference under irrigated conditions (54.2) compared to non-irrigated conditions (48.2). FAO290 hybrid also recorded 54.5 and 52.3 SPAD values for irrigated and non-irrigated conditions respectively. The results indicate that, due to foliar fertilisation, FAO490 hybrid consistently performed better under irrigated conditions compared to FAO290 which performed better under non-irrigated conditions. Therefore, irrigation positively influenced chlorophyll content of the hybrids throughout physiological growth, an indication of interaction between irrigation, foliar fertilisation, and maize growth dynamics.

When both hybrids weren't exposed to foliar application of nutrients under irrigated and non-irrigated conditions. FAO490 and FAO290 hybrids recorded better leaf area index values under irrigation conditions than non-irrigated. FAO490 recorded 7.046 and 5.98, while FAO290 had 6.95 and 5.92 for irrigated and non-irrigated conditions respectively. FAO490 hybrid had a 0.72 and 0.64 NDVI values under irrigation conditions and non-irrigated conditions respectively, while FAO290 hybrid showed that NDVI under non-irrigated conditions (0.77) was slightly better than for irrigated conditions (0.71). SPAD values showed a significant difference between irrigated and non-irrigated conditions for both hybrids. FAO490 hybrid recorded a 19.5% SPAD difference under irrigated conditions (54.56) compared to non-irrigated conditions (45.64). FAO290 hybrid also recorded 54.6 and 52.5 SPAD values for both irrigated conditions and non-irrigated conditions respectively, indicating a positive irrigation effect.

4. Discussion

Physiological growth parameters studied namely, plant height, Leaf Area Index (LAI), SPAD and NDVI significantly increased for three stages (V12, R1, R4) while NDVI, LAI and SPAD significantly decreased at R6 stage in both hybrids under irrigated and water stress conditions. Several studies have recently documented the impact of foliar fertilisation on physiological growth of different plants. Cheah et al. [45], noted the positive impact of zinc foliar application on different physiological growth parameters including plant height, leaf area index and ear grain number. Through foliar application of mineral nutrients, plant growth was optimised as it reduced the gap between nutrient application and absorption by plants [46, 47]. Foliar fertilisation effect on physiological and growth parameters shows the percentage difference between treatment and control mainly under precision irrigation, however there was minimal foliar fertilisation effect noted under non-irrigated conditions at different growth stages. Scholars have noted that using different foliar biofertilizers such as organic seaweed [48], and Ortho Silicic Acid (OSA) [49], positively impacted maize growth and influenced accumulation of dry matter, leaf ratio, relative growth rate, SPAD, and leaf area index. Foliar fertilisation acts as a complementary approach to soil based nutrient application through direct provision of essential mineral nutrients to maize through leaves hence boosting growth and yield [50].

Foliar application of mineral nutrients under precision drip irrigation enhanced photosynthetic efficiency of maize [51]. However, under non-irrigated and water stress conditions, foliar application of mineral nutrients for example nitrogen and potassium enhances stomatal conductance, chlorophyll content, and overall maize plant resilience to stress [20, 52]. The application of silicon-based foliar fertilizers improved maize water use efficiency and drought stress tolerance [53]. This is a clear indication of an interactive effect between several agronomic factors such as foliar fertilisation and irrigation to enhance physiological and growth performance of maize, however foliar fertilisation under non-irrigated conditions has proved vital as it enhances maize growth and tolerance to drought stress conditions.

Foliar application of mineral nutrients under non-irrigated conditions alleviates stress through ensuring nutrient availability at critical growth stages. Plant height and NDVI significantly improved ($p < 0.05$) due to precision drip irrigation while SPAD and leaf area index had no significance difference between the two hybrids. SPAD recorded a significant difference ($p < 0.05$), while Leaf Area Index (LAI), plant height and NDVI had no significant difference between FAO290 and FAO490 under non-irrigated conditions. Both hybrids had better physiological growth performance due to foliar micronutrient applications compared to control under non-irrigated conditions except plant height for FAO290. Foliar K_2SO_4 application ameliorated drought stress effects thus improving maize growth under severe drought stress conditions [54]. When maize was exposed to foliar potassium sulphate application under water stress conditions, a positive effect on maize growth, chlorophyll content and water retention capacity were enhanced [55]. The response of different maize hybrids to foliar fertilisation under different conditions is attributed to genetic diversity, differences in nutrient use efficiency, water uptake, and stress tolerance. High-yielding maize hybrids had a positive foliar fertilisation effect specifically under stress conditions [56]. Hybrid maize genotypes due to their strong efficient rooting system, high rate of transpiration benefited more from foliar application of nutrients hence improved growth [57]. However, it should be noted that several environmental factors play a vital role towards maize hybrid response to foliar fertilisation resulting from nutrient metabolism and genetic adaptation differences [58, 59].

5. Conclusions

Experimental results indicate that foliar fertilisation is vital for crop growth, nutrition and development since it aids easy absorption of nutrients [60]. In this study, foliar application of nutrients influenced the physiological and growth performance of two maize hybrids with different maturity periods (FAO490 and FAO290) exposed to different water regimes (precision drip irrigation and non-irrigated conditions). The growth of maize at different maturity stages showed that plant height, LAI, SPAD, and NDVI significantly increased up to R4 stage but significantly declined at R6 stage. Foliar fertilisation effect on SPAD, NDVI, and LAI under precision irrigated conditions showed that FAO290 had a slightly better physiological and growth performance compared to FAO490. While FAO490 maize hybrid had a better SPAD and LAI fertilisation effect under non-irrigated conditions than FAO290. Plant height wasn't significantly affected by foliar fertilization under non-irrigated conditions for both hybrids. FAO290 maize hybrid showed better physiological and growth performance due to foliar application of nutrients compared to FAO490 maize hybrid especially under irrigation, however with both hybrids showing no significant fertilisation effect under non-irrigation conditions indicates that foliar fertilisation maximised physiological and growth performance under non-irrigated conditions.

AUTHOR CONTRIBUTION

B.S.: conceptualization, investigation, data curation, formal analysis, methodology, writing original draft: A.O.: investigation, validation, and editing, C.B.: project administration, writing-review and editing; J.N.: conceptualization, supervision, methodology, review and editing: A.S: methodology, review and editing: Á.I: methodology, visualisation. All authors have read and agreed to the published version of the manuscript.

Declaration

Conflict of interest

The authors declare that no conflict of interest exists in relation to the published work.

Consent for Publication

All the authors have given their consent of publication.

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