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RESEARCH ARTICLE

Impact of different water regimes on maize grown at two distinctive pedo-climatic locations in Bosnia and Herzegovina

Natasa Cerekovic[1]*, Mihajlo Markovic[1], Vojo Radic[1], Sabrija Cadro[2], Benjamin Crljenkovic[2], Nery Zapata[3], Teresa A. Paco[4], Wilk Almeida[4,5], Ruzica Stricevic[6] and Mladen Todorovic[7]

[1] University of Banja Luka, Faculty of Agriculture, Bosnia and Herzegovina. [2] University of Sarajevo, Faculty of Agriculture and Food Sciences, Bosnia and Herzegovina. [3] Estación Experimental de Aula Dei, Consejo Superior de Investigaciones Científicas (EEAD-CSIC), Zaragoza. Spain. [4] LEAF - Linking Landscape, Environment, Agriculture and Food Research Center, Associate Laboratory TERRA, Instituto Superior de Agronomia, Universidade de Lisboa, Portugal. [5] Instituto Federal de Educação, Ciência e Tecnologia de Rondônia, 76870-000 Ariquemes, Brazil. [6] University of Belgrade, Faculty of Agriculture, Serbia. [7] CIHEAM, Mediterranean Agronomic Institute of Bari, Italy.

***Correspondence** should be addressed to Nataša Čereković: natasa.cerekovic@unibl.org

Abstract

Aim of study: A two-year experiment (2021-2022) was conducted to assess the response of a local maize hybrid BL-43 to different water regimes (full irrigation, deficit irrigation and rainfed) at two distinguished pedo-climatic locations (Aleksandrovac and Butmir) in Bosnia and Herzegovina (BiH).

Area of study: The field experiment was located in Aleksandrovac (near Banja Luka) and Butmir (near Sarajevo) in BiH.

Material and methods: A randomized block design was adopted at both experimental locations with three replicates. An Excel-based irrigation tool was used to manage crop water requirements and irrigation scheduling.

Main results: Crop response to water was affected by site-specific agronomic management, the duration of phenological stages and their interconnection with precipitation events. At both locations, the effect of the water inputs on grain yield was statistically significant confirming the beneficial impact of irrigation. The effect of water stress on yield was particularly pronounced at Aleksandrovac, which was under water and temperature stresses during flowering time. During both seasons and for all water regimes, the total average grain yield was greater at Butmir than at Aleksandrovac for 38% and 27%, respectively.

Research highlights: This is the first experimental study conducted in BiH on the effect of irrigation on maize grain production under different pedoclimatic conditions. The study emphasizes the need for knowledge regarding the impacts that climate change is having on the productivity of one of the region's most important crops.

Additional key words: *Zea mays* L.; irrigation; maize yield; water use efficiency; climate change.

Abbreviations used: AGB (total dry aboveground biomass); AWC (available water content); BiH (Bosnia and Herzegovina); CW (grain weight per cob); D (deficit irrigation); DAS (days after sowing); ET_c (crop evapotranspiration); $ET_{c,adj}$ (crop evapotranspiration adjusted for water stress); F (full irrigation); FC (field capacity); GY (grain yield); HI (harvest index); K_c (crop coefficient); K_s (water stress coefficient); R (rainfed cultivation); RAW (readily available water capacity of soil); TAW (total available water capacity of soil); TKW (thousand kernels' weight); WP (wilting point); YWUE (yield water use efficiency)

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Introduction

Climate change has been affecting the sustainability of agricultural production due to frequent periods of drought and elevated temperatures, especially during the summer season (IPCC, 2022). Increased crop water requirements and limited water availability together with prolonged heat stress can significantly reduce transpiration and photosynthetic rates, shorten the growing season and, therefore, lessen biomass and yield (Jovanovic et al., 2020). Southeast European countries, such as Bosnia and Herzegovina (BiH), are depicted as particularly sensitive to climate change (Vučetić, 2011; Knežević et al., 2018; Stricevic et al., 2018).

Although BiH is a country with a generally humid continental climate, frequent and prolonged droughts have burdened the agricultural sector and put great pressure on agricultural production, especially in summer crops (Stricevic et al., 2018). Several studies confirmed a significant increase in air temperature in BiH in the last few decades (Čadro et al., 2019; Srdić et al., 2023). In the maize-growing season, a statistically significant positive increase in air temperature, in the range of 0.2-0.7 °C per decade, was reported throughout the territory of BiH (Čadro et al., 2019). Moreover, the inter-annual variability of precipitation has risen along with a noticeable increase in the frequency of extreme precipitation events. The main agricultural areas, located in the northeastern and southern parts of the country, are the most vulnerable to summer drought and crop water stress (Čadro et al., 2019; Srdić et al., 2023).

Maize (*Zea mays* L.) is the most widespread and important crop in BiH. Maize cultivation can be severely affected by drought resulting in drastic yield losses worldwide. The Agricultural Advisory Service in Republika Srpska reported a significant loss of maize yield in dry years (https://pssrs.net/ogledi/strna-zita-2-3/?script=lat). The main reason is the lack of adequate irrigation systems and technical support.

Water stress affects both the vegetative and reproductive phases of maize crop growth resulting in a reduction of biomass accumulation and grain yield (Abeledo et al., 2020; Sah et al., 2020; Monteleone et al., 2022; Sheoran et al., 2022). Vulnerability to water stress is particularly high at the flowering and grain-filling stages (Lizaso et al., 2018; Monteleone et al., 2022; Sheoran et al., 2022).

Crop irrigation requirements depend mainly on meteorological conditions and crop growth stage, but soil texture, effective soil depth and fertility require specific irrigation management (Katerji & Mastrorilli, 2009; Katerji et al., 2010). The impact of climate change and water stress on crop water requirements, biomass growth, and yield of maize has been studied in BiH and surrounding regions (Kresović et al., 2016; Mikić et al., 2016; Stricevic et al., 2018, 2021). The results of these studies confirmed (Kresović et al., 2016; Stricevic et al., 2021) water availability and soil fertility as the main factors limiting maize production. Hence, the introduction of irrigation along with efficient nutrient management is needed (Stricevic et al., 2018). However, there is a lack of research investigating how irrigation and optimal nutrient management could alleviate the repercussions of water stress on maize biomass and yield across varying pedo-climatic zones in BiH.

The main objective of this study is to analyse the effect of different water regimes on maize growth at two distinctive pedo-climatic locations in BiH. For this purpose, a common local maize hybrid BL-43, was used. The experiments were done during two years of study with the following specific objectives: (1) to evaluate the agronomic response of the crop at two specific pedo-climatic locations, and (2) to analyse the response of maize growth, dry matter accumulation and grain yield under full irrigation (F), deficit irrigation (D) and rainfed cultivation (R) at Aleksandrovac and Butmir locations.

Material and methods

Experimental sites: location and climate

Field experiments were carried out for two years (2021, 2022) at two locations in BiH: Aleksandrovac (44°58’27.25” N, 17°18’08.43” E) at the Experimental Educational Centre of the University of Banja Luka, and Butmir (43°49’34.0” N, 18°19’19.8” E) at the Experimental Polygon of the University of Sarajevo (Fig. 1). Aleksandrovac is near Banja Luka, in the northeastern part of the country, a continental lowland with an elevation of about 125 m a.s.l. Butmir is located near Sarajevo, in the central hilly area with an elevation of about 512 m a.s.l.

The meteorological data, collected for the period (1961-2020) from the Republic Hydrometeorological Institute of Republika Srpska (https://rhmzrs.com/meteorologija/klimatologija/) and the Federal Hydrometeorological Institute (https://www.fhmzbih.gov.ba/latinica/KLIMA/klimaBIH.php), indicated that Aleksandrovac has a moderate continental climate, with average annual precipitation of 1036 mm, whereas Butmir site is characterized by temperate warm and humid climate with annual precipitation of 942 mm. The average annual temperature is higher at Aleksandrovac (11.3 °C) than at Butmir (10.1 °C). At Aleksandrovac, July is the hottest month, with an average temperature of 21.5 °C, and January the coldest, with an average of -0.3°C. The wettest month is June with an average precipitation of 105 mm. At Butmir, the hottest month is July with an average temperature of 19.6 °C while the coldest is January with an average of -0.3 °C. The wettest month is June with 90 mm of average precipitation.

The long-term average values (1961-2020) of air temperature and precipitation are compared with the data observed during the maize growing season (2021, 2022) for Aleksandrovac and Butmir (Fig. 2). With respect to the long-term averages, air temperature during the growing season at both locations was greater than those 2.1 and 2.3 °C in

2021 and 2022, respectively. The total precipitation during the maize growing cycle in 2021 was higher at Butmir (262 mm) than at Aleksandrovac (234 mm) and it was 46% and 58% of the long-term average, respectively. Precipitation was more evenly distributed at Butmir (74, 25, 21, 62, 45 and 35 mm) than at Aleksandrovac (69, 21, 8, 79, 57 and 1 mm) for April, May, June, July, August and September 2021, respectively. In 2022, the total precipitation during the maize growing cycle was higher at Butmir (374 mm) than at Aleksandrovac (360 mm) and it was about 22% and 36% lower than the long-term average. The total amount of precipitation in 2022 at Aleksandrovac and Butmir was almost 35% and 50% higher compared to 2021.

Experimental locations: soil characteristics

The analysis of the soil physical and chemical characteristics was carried out before the sowing time. Soil profiles were opened to characterize the texture composition and soil water content at field capacity (FC), wilting point (WP), and chemical characteristics (pH, content of organic matter and available nutrients). The gravimetric method was applied for monitoring of the soil moisture content and water balance control. Samples were taken at each plot from a depth of about 30 cm. Total (TAW) and readily (RAW) available water capacity of soil were calculated from the following relation between soil water content at FC and permanent WP:

$$TAW = FC - WP \tag{1}$$

where

$$RAW = TAW^{*}p \tag{2}$$

The depletion fraction threshold (p) for no-stress was fixed to 0.55 of TAW for both locations (Allen et al., 1998).

Aleksandrovac site is characterized by deep (>160 cm) Dystric Cambisol mainly of silty-loam texture, according to BiH National Soil type classification (Resulović et al., 2008) and the World Reference Base for Soil Resources (IUSS Working Group WRB World Reference Base for Soil Resources, 2022). The available water content (AWC) over 1.12 m depth was 242 mm (Table 1). The soil has three defined horizons. The first two have a silty loam textural class, while the last one, located at a depth of 64-112 cm, with a clay content of 34.4%, is classified as a silty clay loam textural class (Table 1). In general, it is a moderately acidic soil (pH in H_2O 5.40-5.55) with a very low organic matter content (<2%). The content of easily accessible potassium is high, and the content of phosphorus is low (Table 2).

The area of Butmir is characterized by Fluvial soil type (Resulović et al., 2008), with a heavier textural

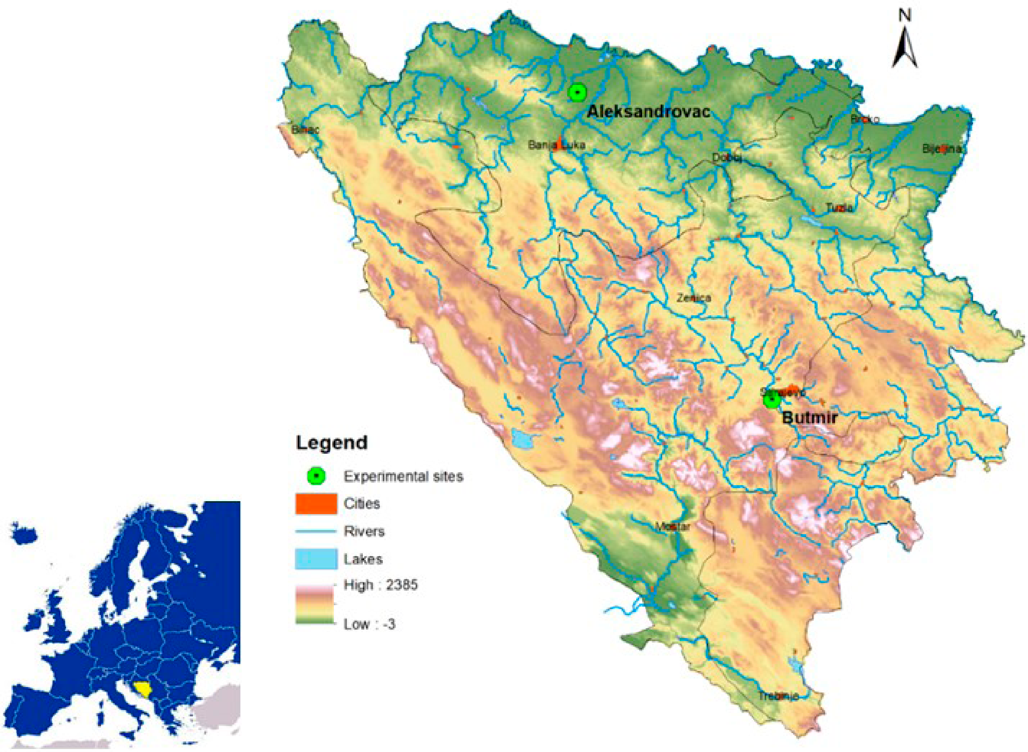

Figure 1. Position of Bosnia and Herzegovina in Europe (http://www.bosnaonline.org/opce-karte-bosne-i-hercegovine) and location of experimental sites.

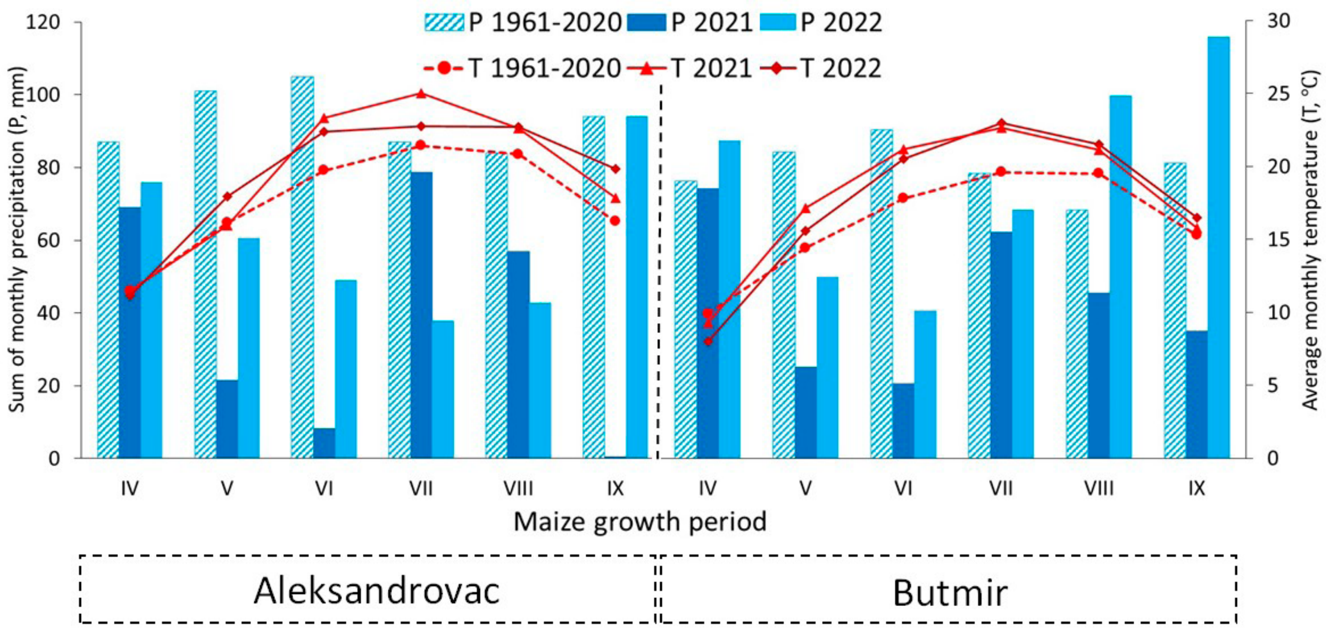

Figure 2. Sum of monthly accumulated precipitation (P) for two maize growing seasons, 2021 (solid dark blue bars), 2022 (solid light blue bars) and the average monthly-accumulated precipitation of the long-time series, 1961-2020 (stripped bars). Monthly average temperature (T) for the maize growing seasons, 2021 (solid red line), 2022 (dashed red line) and monthly average temperature for the long-term series, 1961-2020 (dots line). Values are presented for Aleksandrovac and Butmir experimental locations, BiH.

Table 1. The basic physical and water-related characteristics of the soil profiles at Aleksandrovac and Butmir experimental locations.

Location	Soil layer	Soil texture	Soil depth (cm)	Sand 2-0.02 (%)	Silt 0.02-0.002 (%)	Clay <0.002 (%)	FC (vol, %)	WP (vol, %)	AWC (mm)	SBD (g/cm^3)
Aleksandrovac	I	silty loam	0-39	16.3	58.9	24.7	41.46	21.10	79.40	1.42
Aleksandrovac	II	silty loam	39-64	11.1	60.3	28.5	41.52	19.80	54.30	1.56
Aleksandrovac	III	silty clay loam	64-112	11.5	53.9	34.4	42.54	20.00	108.20	1.53
Butmir	I	clay loam	0-30	37.4	29.1	33.5	43.73	19.98	71.23	1.52
Butmir	II	clay loam	30-40	36.0	31.6	32.4	43.60	20.41	23.19	1.54
Butmir	III	clay	40-60	31.1	25.6	43.3	44.60	28.07	33.05	1.53
Butmir	IV	clay loam	60-120	42.8	19.2	38.0	39.75	30.66	54.53	1.67

FC: field capacity. WP: wilting point. AWC: available water content. SBD: soil bulk density.

composition (clay content of up to 43.3%) and slightly deeper (up to 120 cm), which is equivalent to a Fluvisol (IUSS Working Group WRB World Reference Base for Soil Resources, 2022). The soil has four different layers all with clay-loam textural classes and an AWC of about 182 mm for 1.2 m depth (Table 1). At this location, the soil has a slightly acidic pH in H_2O reaction (6.13-6.35). It has average humus content in the surface layer (2.3%), but the content of humus decreases drastically with depth (Table 2). The content of easily accessible phosphorus is low, especially in the second thin layer (30-40 cm). This second soil layer is characterized by high density and low permeability, because of anthropogenic action, i.e., ploughing and tillage by heavy agricultural machines (plow sole) limited to 30 cm depth. The content of easily accessible potassium is medium (Table 2). No skeleton or rock fragments are present in the soil at both locations.

Table 2. The chemical characteristics of the soil profile at Aleksandrovac and Butmir experimental locations.

Location	Soil depth (cm)	pH in H_20	pH in KCl	Organic matter (%)	Organic C (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)
Aleksandrovac	0-30	5.55	4.20	1.90	1.10	10.50	18.20
Aleksandrovac	30-60	5.40	4.10	1.70	0.99	9.00	16.50
Butmir	0-30	6.13	4.71	2.30	1.33	9.70	12.30
Butmir	30-40	6.25	4.72	1.30	0.75	2.50	12.20
Butmir	40-60	6.21	4.70	1.90	1.10	12.00	8.50
Butmir	60-100	6.35	4.78	0.60	0.35	1.90	7.60

Experimental design and treatments

A randomized block design was adopted at both experimental locations with three replicates to analyse maize response to different water regimes. Three water regimes were applied at both locations: (i) full irrigation (F); (ii) deficit irrigation (D), applying 50% of full irrigation requirements; (iii) rainfed cultivation (R).

The maize (*Zea mays* L., hybrid BL-43) was cultivated at nine experimental plots (3 replicates per 3 water regimes treatments) with a size per experimental plot of 400 m^2 (20 m by 20 m) during 2021 and 2022 growing seasons. The distance in row was 20 cm and between rows 70 cm. All measurements were done inside the 5^{th} row of each plot. At Aleksandrovac, maize was sown on April 22 and 30, emergence took place on May 4 and 10 and harvest was done on September 8 and 15, for 2021 and 2022, respectively. At Butmir, maize was sown on May 9 and 5, emergence took place on May 19 and 17 and harvest was done on October 4 and 5, for 2021 and 2022, respectively.

The maize growing stages were observed directly in the fields. Due to different air temperatures, the sowing was slightly earlier at Aleksandrovac. The total length of all growth stages (initial, crop development, mid-season, late season) during maize growing season at Aleksandrovac was (139, 131, 125 days) in 2021 and (138, 128, 121 days) in 2022 for full, deficit and rainfed water regimes, respectively. At Butmir, the length of growing for F, D and R was respectively 144, 144 and 140 days in 2021 and 147, 146 and 145 days in 2022.

Irrigation and nutrients management

Crop water requirements and irrigation scheduling were managed on a daily basis using an Excel-based irrigation tool (Todorović, 2006). The spreadsheet adopts the FAO56 methodology (Allen et al., 1998) to estimate reference evapotranspiration, crop evapotranspiration, soil moisture in the root zone and irrigation requirements. Daily weather variables (temperature and precipitation) were recorded at the weather stations (iMETOS 3.3) located nearby the experimental fields and used in the soil water balance modelling. Reference evapotranspiration was estimated using the FAO Penman-Monteith approach (Allen et al., 1998). Crop evapotranspiration was determined using the single crop coefficient approach as described in Allen et al. (1998). The crop coefficient (K_c) was fixed at 0.4, 1.2 and 0.35 for the initial, mid-season and late season growing stages, respectively. A maximum root depth of 100 cm was considered at both locations, and it was reached around the flowering stage.

In the case of full irrigation treatment, water was applied before the RAW was depleted and the irrigation doses of 50 mm at Aleksandrovac and 30 mm at Butmir were used. Due to the larger volume of irrigation dose and the small discharge of the drip irrigation system, the irrigation of Aleksandrovac was completed in two days. On the first day, the first dose of 25 mm was applied for full irrigation, while on the second day, 25 mm was applied for deficit irrigation and the second part of the water supply for full irrigation.

The deficit irrigation treatments were irrigated on the same dates as the full irrigation treatments but with the half dose of water. In the case of D and R water treatments, a water stress coefficient (K_s) was used, with $K_s < 1.0$ when soil water depletion in the root zone was greater than *p*. Then, crop evapotranspiration (ET_c) was adjusted for water stress ($ET_{c,adj}$) and computed as:

$$ET_{c,adj}=K_s*ET_c. \tag{3}$$

A drip irrigation system was used and the application efficiency was fixed at 95% (Todorović, 2019). Irrigation was conducted using 16 mm diameter drip lines, with drippers spaced 10 cm apart. In each plot, 22 drip lines were installed, aligning with the number of maize rows. The drippers delivered water at a rate of 1.06 liters per hour. The spacing between the drip lines matched the distance between maize rows, measuring 0.7 m.

The irrigation was stopped a few weeks before harvesting (kernels' physiological maturity) at Aleksandrovac, on August 19 (2021) and on August 10 (2022), whereas at Butmir, on September 9 (2021), and on August 28 (2022).

At Aleksandrovac, net irrigation supply for F was 430 mm in both years while it was 215 mm for D. At Butmir, net irrigation amounts for F were 360 mm in 2021 and 330 mm in 2022, while they were 50% lower for D.

At the Aleksandrovac site, the basic fertilization program for maize for all water regime treatments was 300 kg ha^{-1} of NPK (10:26:26) at tillage (April, 8th, 2021; April 16th, 2022) and 200 kg ha^{-1} of NPK (15:15:15) at sowing (April, 22nd, 2021; April 30th, 2022). The rest of the fertilizer was supplied on two occasions during the maize growing cycle, at six leaf (V6) stage (June 4th, 2021; June 18th, 2022), and at fourteen (V14) leaf stage (July 13th, 2021; July 7th, 2022), with 50.40 kg of ammonium nitrate (AN) at each occasion. The last two fertilizations were applied by fertigation with an irrigation dose of 8.5 mm per plot area. At the Butmir experimental plot, for all water regime treatments, 625 kg ha^{-1} of NPK (7:20:30) fertilizer was applied with the pre-sowing soil preparation (May 3rd, 2021; April 30th, 2022). Additionally, 350 kg ha^{-1} of NPK 15:15:15 were applied at sowing (May 7th, 2021; May 5th, 2022). During the maize growing cycle, fertilization was done at the tenth leaf stage, V10 (July 6th, 2021; July 11th, 2022), with an additional quantity of 275 kg ha^{-1} of calcium ammonium nitrate with 27% N richness.

Quantification of maize growth yield and its components

At harvest, ten plants from each replicate were randomly selected to determine the following parameters: total dry aboveground biomass (AGB), grain weight per cob (CW), thousand kernels' weight (TKW), grain yield (GY), harvest index (HI) and yield water use efficiency (YWUE). The dry AGB was presented for the end of the maize growing cycle. The samples were weighed for fresh weight and dried at 70 °C, until they reached a constant weight. The final yield was taken as the grain mass of the number of cobs per plant multiplied by the number of plants per unit area and expressed in kg per hectare. The HI was calculated by dividing the grain dry mass by the aboveground dry biomass. Water use efficiency per unit of GY was determined by dividing the total yield at 14% humidity by the total amount of evapotranspirated water (ET_c accumulated) during the maize growing cycle.

Data analysis

The data were analysed using SPSS statistical package, IBM SPSS Statistics for Windows, version 22 (IBM Corp., Armonk, N.Y., USA). Analysis of variance (ANOVA) was performed to compare water treatments and seasons of the same location. The analyses were performed for AGB, CW, TKW, GY, HI and YWUE for each location, independently. Differences between locations were not statistically compared since nutrient differences were considered important. In addition, the regression procedure was used to perform stepwise multiple regression analysis of independent variables, irrigation and dependent parameters mentioned above. The ANOVA was performed using Fisher's protected least significance difference (LSD) test at the 95% level of probability. Duncan test was used to identify the means that differ from each other significantly in cases where the ANOVA indicates that there are significant differences between the groups.

Results

Soil water content

The two experimental sites employed different irrigation schedules and doses, with 50 mm per irrigation event (except for first irrigation) at Aleksandrovac and 30 mm at Butmir. At Aleksandrovac, net irrigation supply for full irrigation was 430 mm in both years while it was 215 mm for deficit irrigation. At Butmir, net irrigation amounts for full irrigation were 360 mm in 2021 and 330 mm in 2022, while they were 50% lower for deficit irrigation. The monthly irrigation applied per water regime and the precipitation during the maize growing season are presented in Table 3. The evolution of soil water depletion under different water regimes is shown for both locations and experimental years in Fig. 3.

In the case of full irrigation for both locations and years, soil moisture content was higher than RAW corresponding to the optimum yield threshold. Nevertheless, the irrigation strategy was different. At Aleksandrovac (Fig. 3a), soil moisture content was higher than at Butmir (Fig. 3d) where the soil moisture depletion was close to RAW. In Aleksandrovac, the soil moisture levels remained consistently well above the RAW line (as shown in Fig. 3a and 3g), while in Butmir, the soil moisture levels were closer to the RAW line (as seen in Fig. 3d and 3j).

For the deficit irrigation treatments, at Aleksandrovac site, the maize crop suffered a slight water stress at 31 days after sowing (DAS) in 2021 (Fig. 3b), and at 83 DAS in 2022 (Fig. 3h) due to the precipitation that was higher in 2022 than in 2021. At Butmir in 2021, the crop was stressed since 71 DAS (Fig. 3e), and in 2022 at 67 DAS (Fig. 3k). Differences in water stress between seasons and locations are attributed to precipitation patterns. At both locations, the maize suffers slight water stress at the flowering stage which becomes moderate later in the season. Nevertheless, in both years, precipitation was greater and more regularly distributed at Butmir than at Aleksandrovac.

In the case of rainfed treatment at Aleksandrovac in 2021, water stress began at 21 DAS and it was intensified throughout the maize cycle. (Fig. 3c). However, in 2022, due to large precipitation at the beginning of the growing season, the first water deficit occurred at 60 DAS (Fig. 3i). At Butmir, in 2021, water deficit was observed at 55 DAS (Fig. 3f), reaching severe stress values at the end of the crop season. In 2022, water deficit started at 48 DAS

Table 3. Monthly irrigation depth (mm) during the maize growing period for full, deficit and rainfed water treatments at Aleksandrovac and Butmir in 2021 and 2022. Precipitation (P) was also included.

Year	Location	Monthly precipitation and applied irrigation depth per treatment (mm)					
		Treatments/ precipitations	May	June	July	August	September
2021	Aleksandrovac	Full	30	150	150	100	-
		Deficit	15	75	75	50	-
		Rainfed	-	-	-	-	-
		Precipitation	21.4	8.2	78.6	56.8	0.4
	Butmir	Full	30	30	120	150	30
		Deficit	15	15	60	75	15
		Rainfed	0	0	0	–	–
		Precipitation	25	20.6	62	45.4	35
2022	Aleksandrovac	Full	30	150	150	100	-
		Deficit	15	75	75	50	–
		Rainfed	–	–	–	–	–
		Precipitation	60.6	49	37.8	42.8	94
	Butmir	Full	90	30	120	90	
		Deficit	45	15	60	45	-
		Rainfed	–	–	–	-	–
		Precipitation	49.8	40.4	68.2	99.5	115.6

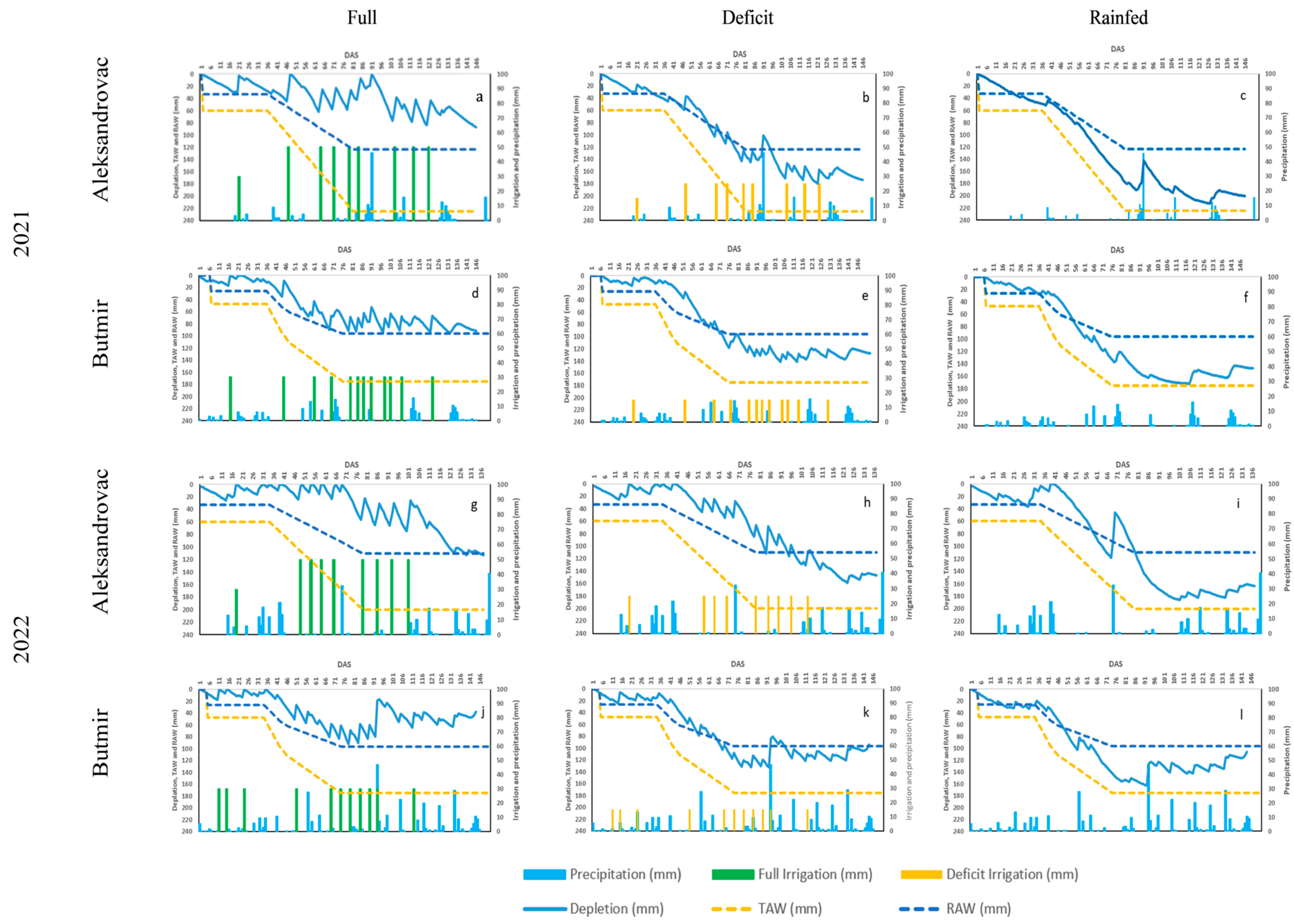

Figure 3. Soil moisture depletion (blue line), total available water (TAW, mm, dashed yellow line), readily available water (RAW, mm, dashed blue line), irrigation (mm, green and yellow bars for full and deficit water regime, respectively) and rainfall (mm, blue bars) for full irrigation, deficit irrigation and rainfed water regimes at Aleksandrovac and Butmir, in 2021 and 2022 maize crop seasons shown in days after sowing (DAS).

(Fig. 3l). At both locations and seasons, the crop was water stressed at end of the season.

The differences between locations and seasons were due to different dates of sowing but especially due to different precipitation amounts and their distribution. A heavy rainfall occurred at both locations on mid-July 2021 that substantially improved the crop water status at both locations. At Aleksandrovac, the precipitation was more than two times than at Butmir (69.2 vs. 33.2 mm). Nevertheless, due to the different sowing dates, the precipitation at Butmir was more beneficial than at Aleksandrovac since it happened around flowering and attenuated the effects of water stress. At Aleksandrovac, the precipitation occurred too late, i.e., two weeks after flowering which reduced its positive impact on biomass and yield. During 2022, a higher and more uniformly distributed precipitation during all crop growth season improved crop water status under rainfed at both locations. Again, the amount of precipitation at Butmir was higher than the long-term average.

Cumulative crop evapotranspiration

Crop evapotranspiration (ET_c) was daily estimated and the cumulative values for all water regimes, both locations and years are presented in Table 4. In 2021, cumulative ET_c value of full irrigated treatment was similar for both locations. Nevertheless, in 2022, cumulative ET_c was slightly higher at Butmir than at Aleksandrovac due to differences in meteorological parameters that influence it at two locations.

ET_c rate did not differ at the beginning of the experiment for both locations, water regimes and years. The difference in ET_c between irrigated and rainfed treatments started after the first irrigation date, around mid-May at Aleksandrovac and at the end of May at Butmir. However, limited water availability affected daily evapotranspiration rate at Butmir at 71, 75 and 54, 56 DAS (silking and 12 leaf's stage, respectively) for D and R treatments in 2021 and 2022 seasons, respectively. The difference in accumulated ET_c was observed between the tasselling and silking stage for all water regimes.

Table 4. Total accumulated evapotranspiration (ET_{c_acc}, mm) during the growing period for full irrigation, deficit irrigation and rainfed treatments at Aleksandrovac and Butmir in 2021 and 2022.

Year	Location	ET_{c_acc} (mm)		
		Full	Deficit	Rainfed
2021	Aleksandrovac	555	482	286
	Butmir	546	443	277
2022	Aleksandrovac	552	462	320
	Butmir	578	436	362

Dry above-ground biomass, cob weight, thousand kernels' weight, grain yield, harvest index and yield water use efficiency

The total dry AGB, CW, TKW, GY and HI were affected by water regime at Aleksandrovac site (Table 5). This was particularly found for GY between all water regimes. However, no difference between water regimes was found for YWUE at this location. At Butmir site, all the yield-related variables, except HI, were significantly affected by rainfed conditions (Table 5). The effect of the year was significant for AGB and TKW at Aleksandrovac, and for AGB, CW, TKW and HI in Butmir. No difference in GY and YWUE efficiency have shown between years at both locations.

In general, the average values of AGB, CW, TKW and GY were higher at Butmir than at Aleksandrovac (Table 6). At Aleksandrovac, a difference between water regimes was found for GY and CW. No difference between F and D water regimes was found for AGB and HI, whereas no difference between all water regimes was found for YWUE. At Butmir, a difference between water regimes was found for AGB. No difference between F and D water regimes was found for GY and TKW, whereas no difference between all water regimes was found for HI. YWUE differed between D and R water regimes.

Discussion

Effect of climate on soil water content and maize crop growth

According to the data presented in Fig. 2, irregular precipitation patterns and a shortage of rainfall at both locations during the maize growth seasons of 2021 and 2022 were observed when compared to the historical long-term average. The precipitation in 2022 was almost double compared to 2021. However, its positive impact on water deficit treatments was higher at Butmir than at Aleksandrovac due to a more regular rainfall regime which support the soil moisture and nitrogen content in the root zone. The monthly average air temperatures were higher from 1.2 up to 3.6 °C compared to long-term data for both years and locations. In 2022 the temperatures were higher than in 2021, considered very warm - extremely above normal- weather conditions. The high temperatures and the water deficit affected maize growth and yield, similarly in different locations (Sah et al., 2020; Monteleone et al., 2022; Sheoran et al., 2022) as well as in all the study region (Stricevic et al., 2018, 2021).

Water stress of the D and R treatments occurred much earlier at Aleksandrovac than at Butmir due to different

Table 5. The p-values and significance of the factors, water regime and year, to explain the variables, aboveground biomass (AGB), cob weight (CW), thousand kernels' weight (TKW), grain yield (GY), harvest index (HI) and yield water use efficiency (YWUE) at harvest. Statistics were presented for Aleksandrovac and Butmir.

Location	Variable	p-values of the factors	
		Water regime	Year
Aleksandrovac	AGB (kg/ha)	<0.001***	<0.001***
	CW (g)	<0.001***	0.619^{ns}
	TKW (g)	0.007**	<0.001***
	GY (kg ha^{-1})	<0.001***	0.867^{ns}
	HI	0.343^{ns}	0.008**
	YWUE	0.336^{ns}	0.590^{ns}
Butmir	AGB (kg/ha)	<0.001***	<0.001***
	CW (g)	<0.001***	0.01**
	TKW (g)	<0.001***	<0.001***
	GY (kg ha^{-1})	<0.001***	0.08^{ns}
	HI	0.019*	0.15^{ns}
	YWUE	0.01**	0.992^{ns}

*, **, *** represent significant differences at p level (p <0.05, p <0.01, p <0.001, respectively). ^{ns} means there is no significant difference.

Table 6. Mean values of grain yield (GY), aboveground biomass (AGB), cob weight (CW), thousand kernels' weight (TKW), harvest index (HI) and yield water use efficiency (YWUE) at Aleksandrovac and Butmir sites, in 2021 and 2022 and for full, deficit and rainfed water regimes are presented. Mean comparison between water regimes and years of the variables was performed with the Duncan test. Similar means are addressed by equal superscript letter (p <0.05).

Location	Factor	Average values and Duncan comparison test					
		GY (kg ha^{-1})	AGB (kg ha^{-1})	CW (g)	TKW (g)	HI	YWUE (kg m^{-3})
Aleksandrovac	Full	10201.8^{a}	24364.6^{a}	182.3^{a}	348.9^{a}	0.5^{a}	1.8^{a}
	Deficit	7946.7^{b}	23139.3^{a}	140.0^{b}	321.4^{ab}	0.5^{a}	1.7^{a}
	Rainfed	5896.6^{c}	13251.6^{b}	102.9^{c}	297.1^{b}	0.4^{b}	1.9^{a}
	2021	8066.5^{x}	16877.3^{x}	138.6^{x}	297.7^{x}	0.5^{x}	1.9^{x}
	2022	7963.6^{x}	23626.4^{y}	144.8^{x}	347.3^{y}	0.5^{x}	1.8^{x}
Butmir	Full	13429.3^{a}	31072.0^{a}	279.7^{a}	352.1^{a}	0.5^{a}	2.3^{ab}
	Deficit	13072.9^{a}	26020.7^{b}	281.5^{a}	286.7^{b}	0.5^{a}	2.7^{a}
	Rainfed	6651.7^{b}	21368.5^{c}	164.2^{b}	288.9^{b}	0.5^{a}	1.9^{b}
	2021	10346.5^{x}	21488.3^{x}	216.2^{x}	264.2^{x}	0.4^{x}	2.3^{x}
	2022	11756.0^{x}	30819.1^{y}	267.4^{y}	354.3^{y}	0.6^{y}	2.3^{x}

sowing dates, precipitation patterns and irrigation schedules. The period of water stress at Aleksandrovac started around the tasseling and influenced maize development and yield more than at Butmir. Zhang et al. (2019) found that increasing the frequency of irrigation events (keeping the volume constant) there was an improvement in crop yield. Butmir applied a higher-frequency lower-dose irrigation schedule compared to Aleksandrovac, that can explain the higher yield.

At Butmir, as a result of soil characteristics, especially its depth and the presence of a highly compacted layer or plow sole at a depth of 30 to 40 cm, the use of water in the complete soil profile, as well as the capillary rise of water was limited, i.e., slowed down. During the germination and early root growth periods maize plants had enough water and nutrients for growth. During the root development the lack of water affected the weak development of the roots for non-irrigated plants, which reflected the growth of maize under rainfed conditions. In such conditions, maize under F and D water regimes had the possibility of faster initial development and of ensuring sufficient strength for partial penetration through this compacted soil layer. However, maize under R water regime in the initial period of 2021 did not receive a sufficient amount of precipitation as in 2022 and slowed growth as well as restrained the mass of roots in the surface layer of the soil up to 30 cm. It has already been found that biomass accumulation and morphological traits in plants are influenced by soil texture and evapotranspiration, closely related to crop growth and yield productivity (Katerji et al., 2010; Monteleone et al., 2022).

Crop evapotranspiration under different water regimes

Irrigation started when the RAW was depleted, on May 10 and 17, 2021, and on May 18 and 18, 2022, at Aleksandrovac and Butmir, respectively. Maize under rainfed conditions presented water stress already in the initial growth stage (May), reducing the evapotranspiration rate at both locations, especially at Aleksandrovac. At the initial stage, ET_c was mainly related to soil evaporation since the crop coverage was rather poor and soil evaporation was the main component of total ET_c (Allen et al., 1998). Total accumulated evapotranspiration increased with raising water use in the experiment, and for F and D water regimes had a similar value as shown in previous studies in the region (Vučetić, 2011; Pejić et al., 2020; Stricevic et al., 2021). However, with optimal use of precipitation and water reserves in the soil, maize crop reached evapotranspiration from 545 to 578 mm in the maize growing period, while in other studies in the region, ET_c is reported between 472 and 570 mm.

In temperate climate conditions, it is difficult to achieve a defined deficit water regime, due to precipitation events that occur during all crop growth period. In such climate conditions, irrigation is often only an additional measure (supplemental irrigation). Deficit irrigation means that maize received approximately less irrigation water as previously defined, but due to soil water storage and precipitation, total ET_c does not follow % of recommended water amount for the deficit irrigation regime. It should be noted that the deficit water regimes have higher precipitation use efficiency in comparison with the full water regime.

Water stress at both locations affected maize crop evapotranspiration as shown in the accumulated ET_c at the end of the maize growing period which is in line with results obtained in other studies (Vučetić, 2011; Djaman et al., 2018; Pejić et al., 2020). In particular, water stress that occurred before and during tasseling and reproductive stage affected crop growth (Djaman et al., 2013; Kresović et al., 2016).

Total biomass and grain yield under different water regimes

In future climate conditions, maize growth and development could be more affected by drought and heat stress (Lizaso et al., 2018; Li et al., 2022). Water availability is a crucial factor that affects maize production. In this study, water deficit treatments significantly reduced biomass accumulation, grain CW, TKW and GY as it was already shown in the literature (Abeledo et al., 2020; Sah et al., 2020; Monteleone et al., 2022; Sheoran et al., 2022).

Water deficit accompanied with high temperature and low air humidity at flowering was observed at Aleksandrovac for all treatments which strongly impacted the biomass and yield. Maize growth for this hybrid at Aleksandrovac location showed lower biomass accumulation, cob weight and GY compared to an average year (GY=13,300 kg ha^{-1} were reported in other works: http://www.poljinstrs.org/sr-YU/zavodzakukuruz/zk-domaci-hibrid-bl-43.html). The GY at Butmir was in average 31.64, 64.51 and 12.80% higher compared to Aleksandrovac for F, D and R water regimes, respectively. It can be attributed to higher nutrient inputs and a more regular precipitation pattern which reduces N leaching from the root zone. Extremely high temperatures at the critical stage of maize development such as flowering affected the final yield, as observed in other studies worldwide (Paredes et al., 2014; Hütsch & Schubert, 2017; Sah et al., 2020). Moreover, pedoclimatic and management differences, such as different soil characteristics (Tolk & Evett, 2012), local climatic conditions (https://www.fhmzbih.gov.ba/latinica/KLIMA/klimaBIH.php), as well as the amount of applied fertilizer (higher in Butmir) could attributed to the final yield difference between locations.

The final yield under F and D water regimes at Butmir location reflected the optimal use of water and nutrient resources under these pedo-climatic conditions. The highest yield at Butmir could be explained by the use of more assimilates for grain production at maturity (Abeledo et al., 2020). The ability of hybrids to use efficiently precipitation and nutrients is very important, especially after the silking stage. This also could help to increase the kernel number per plant, enhance a biomass allocation to reproductive sinks and improve GY (Wang et al., 2011; He et al., 2017). Maize can be tolerant during the vegetative growth stage while the greatest impact on crop growth may be due to soil moisture and nutrients deficit accompanied by high temperature during the flowering period and grain filling stages (He et al., 2017; Lizaso et al., 2018; Monteleone et al., 2022; Sheoran et al., 2022; Wang et al., 2022).

Yield water use efficiency and harvest index at two distinctive pedo-climatic locations

Maize is a C4 crop and higher values of YWUE compared to C3 crops were expected due to the higher potential to capture radiation, water, N and CO_2. The values of YWUE reported in this study agree with those reported in the literature for similar pedo-climatic conditions (Pejić et al., 2011; Rodić Trifunović et al., 2015), i.e. in a range of values (1.7-2.7 kg m^3). These values confirm that YWUE for maize grown under water deficit could be as high as in fully irrigated plants. The lower YWUE for all water regimes in Aleksandrovac and R conditions in Butmir (1.7-1.9) kg m^3 compared to those observed in the region (Pejić et al., 2011) could be connected to the extreme drought under rainfed conditions in Butmir and drought accompanied by high temperature during the experimental seasons in Aleksandrovac. The authors suggested that according to the studies from 1976-2006, good water use efficiency was mostly achieved under irrigation conditions, where the values range in the largest number, over 2.5 kg m^{-3}, while under conditions of natural water supply, it was observed greater variation (from 1.4 to 2.5 kg m^{-3}). The total GY of maize was improved with irrigation, although the reduced (limited) water application especially for D water regime at Butmir showed higher YWUE (2.7 kg m^3). This can be attributed to the soil spatial variability, which at some plots affected the soil moisture availability. It was more evident in deeper soil layers where the plant was able to explore it. For instance, high values of YWUE over 3 kg m^{-3} were found in other studies in the region (Rodić Trifunović et al., 2015) and worldwide (Djaman et al., 2013, 2018).

This study was performed at two distinctive pedo-climatic locations, where the degree and duration of water and temperature stress during different crop growth periods played an important role in YWUE. Therefore, specific weather conditions, agronomic management (nutrient inputs) and soil hydraulic characteristics may be a reason for YWUE difference between locations. Katerji & Mastrorilli (2009) found that soil texture might have a potential effect on YWUE. Although YWUE may increase in limited water conditions, careful water management and a suitable soil texture should be considered for improving YWUE and final yield (Tolk & Evett, 2012).

A close positive correlation between dry matter accumulation and GY has been already reported in the literature for maize production (Paredes et al., 2014; Abeledo et al., 2020). HI increases when the crop allocates more assimilates to grain and less to the rest of the biomass which could be influenced by water regimes (Unkovich et al., 2010). The values found in our study in general were similar to those reported in the literature for well irrigated maize (0.5). However, for rainfed conditions at Aleksandrovac, a smaller value of HI was found (0.4). The advancement or delay of flowering due to the different irrigation treatments may have caused high temperatures to affect plants of one irrigation treatment more than the other. As the HI can vary due to environmental changes, higher HI for 2022 (0.6) compared to 2021 (0.4) at Butmir could be a result of more biomass accumulation related to grain mass accumulation, which could be due to the difference in precipitation between the years. Maize grown under deficit irrigation experienced water stress and in this condition the plant should allocate a greater portion of their resources to maintain basic physiological functions and survival rather than to the development of the grain. Therefore, maize HI was influenced by the temperature, the amount of precipitation and their seasonal distribution, as well as by the water availability during the crop's most sensitive growth period (Unkovich et al., 2010; Ion et al., 2015; Hütsch & Schubert, 2017).

Conclusions

This study represents a first attempt to demonstrate the importance of experimental findings related to maize growth under different water regimes at two distinctive pedo-climatic locations in Bosnia and Herzegovina. In as much as a local hybrid (BL-43) resistant to drought is tested, the benefits and requirements of maize irrigation were confirmed, along with a need for appropriate nutrient management. In both locations, the effect of the irrigation water regime was statistically significant in maize GY, confirming the beneficial impact of irrigation in temperate climate zones such as that of BiH. A lower yield for this hybrid was found at Aleksandrovac compared to Butmir, which might be explained by extreme drought and temperature stress that occurred during the most sensitive period of growth and by limited fertilizers' inputs. The effect of multiple abiotic stresses such as increased temperature and water stress on maize crop response should be discriminated to keep the GY stable under changing climatic conditions (decrease and variability of precipitation and increase of air temperature). A deeper understanding of pedo-climatic characteristics and crop parameters is essential to properly address the irrigation scheduling and nitrogen inputs in the areas characterized by temperate climate and non-homogeneous soils. It is particularly important to evaluate the potential of maize hybrids under different water and nitrogen inputs under slight to moderate water stress conditions. In this context, the present research on a local hybrid can support further selection of drought stress tolerant hybrids for different pedo-climatic conditions of Bosnia and Herzegovina.

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