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Grain yield and water use efficiency of maize as influenced by different irrigation regimes through sprinkler irrigation under temperate climate

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ABSTRACT

In Vojvodina region, water deficit during the growing season is a major factor limiting maize production. Therefore, to achieve the ideal soil water content in this region, it is of crucial importance to optimize irrigation. The effects of different irrigation levels with sprinkler irrigation system on crop yield, yield components, water use, water (WUE) and irrigation water use (IWUE) efficiency of maize (*Zea mays* L.) were investigated in Vojvodina (northern Serbia), on a Calcaric Chernozem soil in temperate environment for 3 consecutive years (2006–2008). Maize was subjected to four irrigation regimes, as follows: non-limited irrigation (I_{100}), 75% of non-limited irrigation (I_{75}), 50% of non-limited irrigation (I_{50}), and rainfed (non-irrigated) as the control (I_0). The irrigation treatments were arranged in a complete randomized block design with 4 replicates. Results showed that maize grown in rainfed conditions had high annual variability, mainly due to amount of rainfall and its distribution during the crop-growing seasons. A significant irrigation effect was found for yield, yield components and others investigated parameters under study. Water stress had significant impact on yield response: as an average of the three years, a grain yield increase of 47.8, 32.8, and 22.9% was observed in I_{100}, I_{75} and I_{50} treatments compared to rainfed (I_0) treatment, respectively. Yield increased linearly with seasonal crop evapotranspiration and irrigation amount. Furthermore, WUE is maximized with a moderate water deficit (I_{50}), while IWUE is the highest in I_{100} treatment. The deficit irrigation stress index, DISI, decreased with increasing irrigation rate. The results revealed that irrigation is necessary for maize cultivation because rainfall is insufficient to meet the crop water needs in Vojvodina. In addition, the study indicated that the irrigation regime of 25% water saving (I_{75}) could ensure satisfactory grain yield of maize and increment of WUE.

1. Introduction

In Vojvodina, a northern part of the Republic of Serbia, maize (*Zea Mays* L.) is a dominant field crop grown, on average, in 0.65 million hectares per year, or about 42% of the total arable land area. During the past four decades (1974–2012), maize grain yields varied between 2.1–7.5 t ha^{-1} (Statistical Office of the Republic of Serbia, 2012) depending on the year. In this region maize is mainly grown under rainfed conditions. However, high rainfall variability in this region means that its yield is highly variable from year to year. Under the environmental conditions of Vojvodina, there is usually a close connection between low maize yields and precipitation deficit, especially during June, July and August (Kresovic et al., 2014). Similar findings were observed in the US Corn Belt (Shaw, 1988). During that period, in which maize passes through phenological stages of flowering, pollination and grain filling, its sensitivity to drought was high and could cause yield reduction. Under such climatic conditions, maize productivity depends to a high extent on irrigation supplies. Irrigation water is limited resource in many areas of South East Europe due to climate change. Especially adverse impacts of global climate change on crop production are expected in the Pannonian Plain (Olesen et al., 2011) which includes the most important agricultural region of Serbia (Vojvodina). Consequently, an appropriate choice of irrigation scheduling to maximize WUE is needed.

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Table 1
Main physical and chemical properties of the soil at the experimental site.

Soil depth (cm)	Particle size distribution (%)			Bulk density ($g\,cm^{-3}$)	Field capacity (vol%)	Wilting point (vol%)	Available water (vol%)	pH (1:2.5 H_2O)	$CaCO_3$ (mas%)	Organic matter (%)	P_2O_5 ($mg\,kg^{-1}$)	K_2O ($mg\,kg^{-1}$)
	Clay	Silt	Sand									
0–10	30.5	64.8	4.7	1.17	29.1	14.5	14.6	7.76	3.6	2.9	660	230
10–20	26.3	69.8	3.9	1.24	33.1	15.4	17.7	7.69	5	3.07	660	270
20–30	26.1	69.2	4.7	1.25	35.5	15.7	19.8	7.76	5.4	2.96	410	230
30–40	27.2	69.1	3.7	1.41	38.5	14.5	24	7.77	5.7	2.87	350	170
40–50	26.8	68.4	4.8	1.26	38	15.3	22.7	7.91	21.3	1.74	80	90
50–60	26.4	68.1	5.5	1.29	36.9	14.5	22.4	7.93	24.1	1.4	90	70

High sensitivity to drought and other environmental stresses have been reported for maize (Pandey et al., 2000; Çakir, 2004). Many researchers have evaluated the effects of water on maize yield and yield components. Also, related parameters such as water use efficiency (WUE) and irrigation water use efficiency (IWUE) are reported (Howell, 2001; Di Paolo and Rinaldi, 2008; Farré and Faci, 2009; Mansouri-Far et al., 2010; Paredes et al., 2014). Irrigation affects maize grain yield; the highest yield is obtained with a complete restitution of crop evapotranspiration, even though WUE, as well as IWUE, declines with an increase in irrigation water amounts. According to English and Raja (1996), the vital aim of appropriate irrigation water application is to increase water productivity.

In Bushland (TX) region, Yazar et al. (1999) studied the effect of 6 different irrigation levels on LEPA technique irrigated maize stress levels and grain yield. These authors found that highest yield, WUE and dry matter were obtained from both the fully irrigated treatment and that receiving 80% of the estimated irrigation requirement. In sub-Saharan environment, Pandey et al. (2000) found a linear grain yield response for maize with deficit irrigation.

Payero et al. (2006) have studied the response of maize to deficit irrigation in the semi-arid environment of the US Great Plains. No beneficial increase was found in WUE in that environment with deficit irrigation, because the WUE increased linearly with the ratio of actual crop evapotranspiration on potential crop evapotranspiration.

According to Doorenbos and Kassam (1979), after growth stages of a particular cultivar under local climatic and soil conditions are identified, irrigation scheduling allows for maximizing crop yield and using efficiently scarce water resources. In the case of insufficient natural water supply, use of deficit irrigation in dryland conditions is recommendable. However, deficit irrigation may have variable effects for the same crop, depending on the location. Deficit irrigation can be applied correctly only with a thorough understanding of the yield response to water (English, 1990). Hence, the aim of this research is to evaluate the effects of different irrigation amounts applied with sprinkler system on grain yield, certain yield components and WUE of maize under Vojvodina conditions. This information can be helpful for the regional growers to save water in maize cultivation through the choice of appropriate irrigation scheduling.

2. Materials and methods

2.1. Site description and climate

The field experiments were conducted in Zemun Polje, in the vicinity of Belgrade (Serbia) (44°52′ lat. N; 20°20′ long. E, 81 m a.s.l.) in 2006, 2007 and 2008 at the experimental site of the Maize Research Institute "Zemun Polje".

The soil in the experimental site was Calcaric Chernozem, silty loam texture. The main physical and chemical characteristics of the soil in the study area are shown in Table 1.

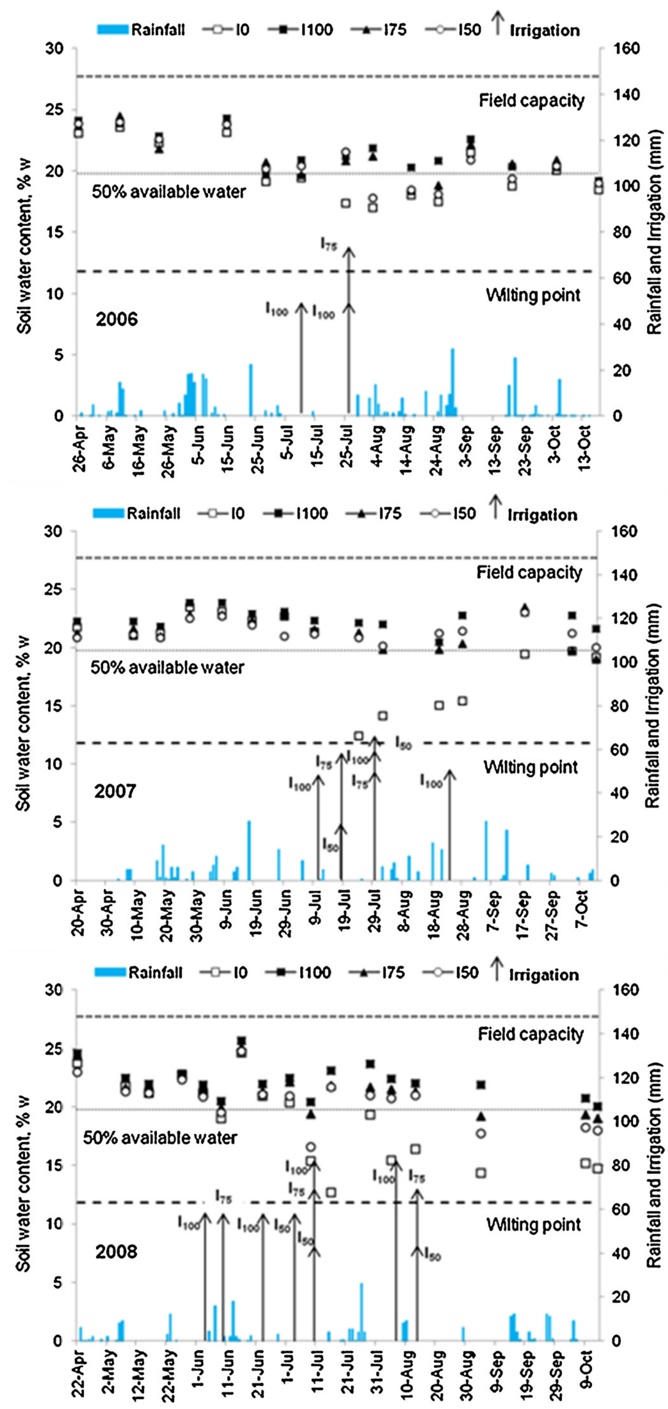

Fig. 1. Seasonal variation of soil water content under different irrigation treatments in 0–0.60 m soil depth, daily rainfall and irrigation.