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DEFICIT IRRIGATION OF SOYBEAN (*GLYCINE MAX*. (L.) Merr.) BASED ON MONITORING OF SOIL MOISTURE, IN SUB-HUMID AREA OF EASTERN CROATIA

Monika Marković[1*], Marko Josipović[1], Marija Ravlić[1], Ana Josipović[1], Vladimir Zebec[1]

[1]University of J. J. Strossmayer in Osijek, Faculty of Agriculture, Department for plant production and agricultural amelioration, Kralja P. Svačića 1d, 31000 Osijek, Croatia

[2]Agricultural Institute in Osijek, Department for agricultural techniques, J. Predgrađe 17, 31000 Osijek, Croatia

[3]Agricultural Institute in Osijek, Department for Breeding and Genetics of Industrial Plants
*Corresponding author. Monika.Markovic@pfos.hr

ABSTRACT

Deficit irrigation of soybean was induced by irrigation at 60-100% field water capacity (FWC) during three different climatic years in sub-humid area. Crop evapotranspiration (ETc) was measured for each irrigation plots, dry-land (a1), deficit irrigation (a2) and full irrigated plots (a3). Average across years ETc totalled 46.05 mm/dec from initial to late stage. Kc values ranged from 0.35 at vegetative stage, 1.0 at reproductive stage after what it declines to 0.82. In deficit irrigated plots grain yield of soybean was increased as compared to control plots by 7.5% (2006), 1.15% (2007) and 7.3% (2008). In average climate years (2006 and 2008), by increasing soil water content at full irrigated plots (80-100% FWC), grain yield of soybean was reduced by 1.9% (2006) and 5.8% (2008) in comparison to deficit irrigated plots. This was in contrast to results obtained in extremely warm and very dry year 2007, when the highest yield was at full irrigated plots (3.68 t ha^{-1}). Averaged across years, the highest irrigation water use efficiency was at deficit irrigated plots (0.3 to 3.3 kg m^{-3}). Results obtained from this research showed that deficit irrigation management is an efficient measure for preserving water resources and achieving high yields in average climate years.

Key words: deficit irrigation, *Glycine max.* (L.) Merr., evapotranspiration, IWUE.

INTRODUCTION

Due to economic and agrotechnical importance, soybean (*Glycine max.* (L.) Merr.) occupies one of the leading places on production areas in the world. According to data provided by FAO (2008), an increase in soybeans production in the Republic of Croatia was noted (2001 = 41621 ha, 2011 = 60000 ha). In the period between the year 2000 and 2011, the average yield of soybeans in the Republic of Croatia was 2.38 t ha^{-1}. The minimum yields of 1.4 t ha^{-1} (2000) and 1.7 t ha^{-1} (2003, 2007) came as a consequence of unfavourable weather conditions for soybean production, most of all the lack of rainfall, as well as unfavourable distribution of rainfall during the growth period. Although Croatia has abundance in clean drinking water, and stands at the top of the water resources scale in Europe, it stands last concerning irrigated area in Europe, and in the world. Yet the analysis of weather condition for region of eastern Croatia showed a need for supplemental irrigation. Šoštarić et al. (2013) reviewed weather conditions with the use of hydrotermic coefficient by Seljaninov for the last eighteen years (1994-2011) of Osijek area (eastern Croatia). Six years were dry, while five years were extremely dry. Such a phenomenon of extreme weather conditions suggests a more rational water resources management or the best management practice for water-efficient irrigation. One of the irrigation strategies which preserves water and maintains the yield is regulated deficit irrigation (RDI), a controlled water deficit strategy which should be adopted to a certain environmental demands, crop and management practices (Kang et al., 2000; Perry, 2007). The meaning and features of deficit irrigation in different climate zones and possible consequences of DI have been subject of previous research of Fereres and Soriano (2007). Authors claimed that there is potential for improving water productivity in

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many field crops by choosing the best DI strategy for many situations (climate zones, source of water, crop and growth stage). Karam et al. (2005) examined response of soybean yield to deficit irrigation stress. They measured ET by lysimeter in irrigated and dry-land conditions. Deficit irrigation was made by delaying irrigation for two weeks during different growth stages (full bloom, grain enlargement and at mature grain) and control was full irrigated plots. They found that the most significant grain yield reduction (28%) happened in deficit irrigation during grain enlargement stage. They also found that water use efficiency (WUE) at DI regime was up to 13% higher compared to control. WUE is affected by soil moisture level. When water is limited (drought or deficit irrigation regime) WUE is higher (Burriro et al., 2002; Ouda et al., 2007). Since water use efficiency (WUE) in the narrow sense does not take into concern the role of irrigation, the term irrigation water use efficiency (IWUE) was introduced. IWUE is more suitable in agronomical practice, because it takes into concern the change in yield, depending on various irrigation regimes (Howell, 2006; Blümling et al., 2011). The objective of this study was to examine the impact of DI regimes induced by irrigation at 60% of field water capacity on the yield of soybean and IWUE in different irrigation schedules based up on monitoring of soil moisture. Furthermore, the objective is to provide information on the DI in sub-humid areas where irrigation has been used to supplement rainfall during the periods of drought or unfavourable distribution of rainfall.

MATERIAL AND METHODS

Research took place at trial field of the Agricultural institute in Osijek (45°32" N and 18°44" E, altitude 90 m), eastern Croatia using a randomized complete block design with three replications. The size of the trial plot was 405 m^2. Three irrigation regimes (Table 1) were studied in period 2006-2008. Regimes included a1 = dry-land; a2 = deficit irrigation (limited to 60-100% of field water capacity, FWC); a3 = full irrigation (80-100% FWC).

Table 1. Irrigation regimes in growth period (2006-2008)

Year	a2 (deficit irrigation)			a3 (full irrigation)		
	Irrigation time	n	mm	Irrigation time	n	mm
2006	14, 21 July	2	80	14, 21, 28 July	3	120
2007	1, 15 July and 1 August	3	120	15 and 29 June, 12 and 20 July, 5 August	5	200
2008	10, 19 July	2	80	17, 28 July and 5 August	3	120
n = number of irrigation intervals; long-term average = 1961-1990						

Timing of irrigation, based on the amount of available water in soil, was given with Watermark Soil Moisture Sensor 200SS, which were buried in the soil after the sowing of the soybeans. Watermark sensors were calibrated to soil on a trial plot by gravimetric measurements and sensor readings. The readings ranged from 0-199 cbar (0 stands for wet soil (100% FWC), while 199 cbar stands for dry soil). In a3 irrigation plots (full irrigation) the irrigation time has 40 cbar of value, which represents a usual value (30-60 cbar). In a2 plots of irrigation (deficit irrigation) the irrigation timing has a value of 60-80 cbar. Soil water measurements were made every two to three days, depending on the rainfalls and irrigation intervals. Soil moisture sensors were buried at 10-15 cm and 25-30 cm, the effective rooting zones. Although there are some cultivar differences in root development, according to previous researches 70-80% root length density of soybean (Garay and Wilhelm, 1983; Mayaki et al., 1976) occurred in upper soil layer (<30 cm). Expressed as DM 70-80% of roots were found in 0.15 surface. Root distribution of soybean is not water stress dependent. Water deficit will not affect the relative soybean root distribution, because approximately 97% of the total roots will be at the surface 0.23 m, regardless of irrigated or dry-land conditions (Benjamin and Nielsen, 2006). Each irrigation plot (a1, a2, a3) was irrigated and equipped with two moisture sensors at two levels and three replicates (18 sensors in total). There was no limitation in water use during the vegetation (2006-2008). Since it was irrigated directly from groundwater, it was possible to design the irrigation regimes before vegetation and to adjust timing and amount of water. Soybeans were irrigated using a self-moved sprinkler system. The pressure on the water entrance was 5 to 7 kPa, 3 to 4 kPa on the nozzle. The amount of water added with sprinkler system depends on the diameter of the nozzle, working pressure, and the speed of the system (12 cm/h). Water was pumped from a well (19 m of depth) and analysed for quality. According to water quality guidelines (FAO, 1985) there is slight to moderate restriction on use. Weather data were used as input for Penman-Montheith equation (Allen et al., 1998) for calculating reference evapotranspiration (Eto). Crop evapotranspiration (ETc) was calculated by using a Kc coefficient for each stage of soybean development (initial-late). Evapotranspiration in the plots was calculated using a soil water balance model according to Doorenbos and Kassam (1979). Effective rainfall was calculated according to USDA S.C.S. Method (Kent, 1973) Soil at the experiment location is eutric cambisol (Soil Survey Division Staff, 1993), classified as deep soil, fine textured, with water table below 250 cm during vegetation period in average years. In extreme years with rainfall above average, underground water rise up to 150 cm. Soil retention water capacity is approximately 40% volume in upper soil layer (to 30 cm). pH in KCl varies from 6.5 to 6.9, P2O5 volume is 22.6 to 26.4 mg per 100 g/soil, K2O of the volume is from 30.4 to 36.5 mg per 100 g/soil. Capillary flow to the root zone was assumed to be negligible. Weather data were collected from Meteorological and Hydrological Service, and included minimum and maximum air temperatures, wind speed, rainfall, relative humidity and solar radiation on daily basis The climate in eastern Croatia is a moderately warm and rainy continental one (Cfa, Köppen climate classification). Irrigation efficiency (IE) was calculated with the use of the term IE = Yi / Yd x 100 (Takac et al., 2008) where Yi stands for the yield of the soybeans on irrigated plots (a2 and a3), Yd = yield of the soybeans on dryland plots (a1). Irrigation water use efficiency (IWUE) was calculated using the term IWUE = Yi – Yd / I (mm) where Yi stands for the yield of the soybeans on irrigated plots (a2 and a3), Yd yield of the soybeans on dry-land plots (a1) while I stands for the amount of water supplied by irrigation (Boss, 1979). The yield of the soybeans was converted to 13% of moisture. Statistical analyses included ANOVA and were carried out through the Statistica 7 (Statsoft). The treatment means were compared using the LSD test ($p<0.05$, $p<0.01$).

RESULTS

Figure 1 shows that amount of rainfall in June (2006, 2007, 2008), July (2006, 2007) and August (2007, 2008) was insufficient for soybean needs. Rainfall in July of 2006 and 2007 was by 78% and 58% lower than average. During the second year of experiment, rainfall (April-September) was 38% lower than average and it represented 62% of total crop water requirements. The amount of effective rainfall was almost the same for year 2006 and 2008 (341.4 and 346.8 mm), when there was enough of rainfall for plant production, although badly distributed during growth season. For example, in year 2006 only 14.6 mm of rainfall was in month July and 133.5 mm in August (Figure 1) which is 285% higher as compared to the long-term average for this region. Average weather conditions for eastern Croatia during the months of April to September from 2006 to 2008 are shown in Table 2. Data used for calculating reference evapotranspiration (ET_o) for growth period. ET_o ranged from 3.1 (2006 and 2008) to 3.4 mm/day (2007). On average, the 2007 growth season had the lowest amount of rainfall, relative humidity and highest air temperatures which resulted in highest value of ET_o, which was for 9.7% higher than during 2006 and 2008 (Table 2). During summer time in year 2007 the highest value of ET_o ranged from 4.1 (June) to 4.4 mm day^{-1} (August).

Yet analysis of months for each tested years showed that the highest ET_o occurred in July of 2006 (4.6 mm/day), when solar radiation was very high (25.7 MJ m^2/day) and efficient rainfall was only 14.3 mm. The analysis of weather conditions for tested years suggested need for suppleme ntal irrigation, which is described as a tactical measure during drought to stabilize production (Debaeke and Aboudrare, 2004). The irrigation strategy is described in table 2.

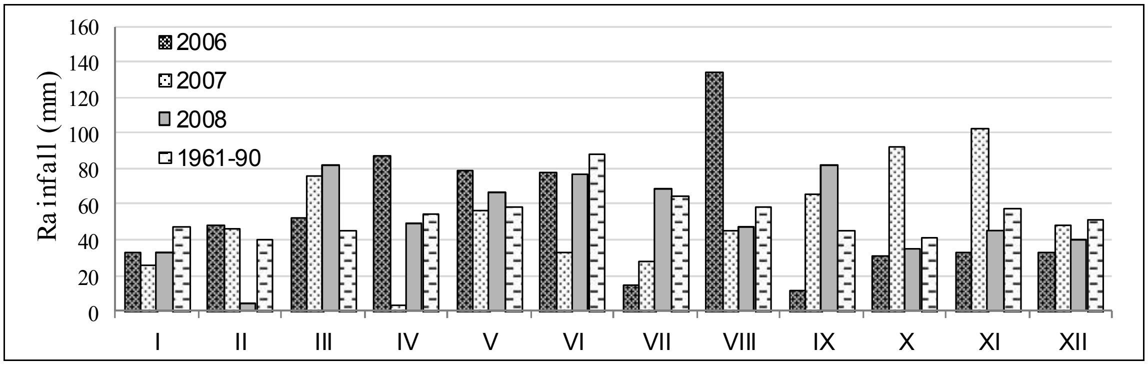

Figure 1. Amount of rainfall from 2006 to 2008 and long term average (1961-90) for Osijek region

Table 2. Average of minimum (T_{min}) and maximum (T_{max}) air temperature (°C), relative humidity (RH), wind speed (WS), effective rain (mm) and reference evapotranspiration (ET_o) for the growth period at Osijek (2006-2008)

Year	Month	T_{min} (°C)	T_{max} (°C)	RH (%)	WS (m s^{-1})	Sun hours	Rad (MJ m^2 day)	ET_o (mm/day)	Eff. rain (mm)
2006	IV	7.7	18.7	71	3.1	6.1	15.9	2.0	74.7
	V	10.8	22.3	66	2.9	8.1	20.6	3.1	68.7
	VI	14.7	25.6	68	2.7	8.6	22.1	3.7	68.3
	VII	17.0	30.7	61	2.3	11.7	25.7	4.6	14.3
	VIII	14.6	25.4	76	2.6	6.6	17.4	3.1	105.0
	IX	12.3	24.7	71	2.4	7.7	15.5	2.3	10.7
Average		*12.9*	*24.6*	*69*	*2.7*	*8.1*	*21.5*	*3.1*	*341.4*
2007	IV	5.6	21.5	53	2.7	10.5	21.3	2.6	2.9
	V	12.3	24.9	64	2.9	8.5	21.1	3.3	51.1
	VI	15.9	29.3	62	2.5	9.6	23.5	4.1	31.5
	VII	15.8	31.9	53	2.7	11.1	24.9	4.4	23.7
	VIII	16.2	30.1	62	2.6	9.5	20.9	3.8	41.8
	IX	9.4	21.3	71	2.8	6.5	14.2	2.1	58.4
Average		*12.5*	*26.5*	*61*	*2.7*	*9.3*	*21.0*	*3.4*	*209.4*
2008	IV	7.1	18.8	69	3.5	5.9	15.7	2.0	45.0
	V	11.5	24.9	61	2.8	9.2	22.0	3.4	59.7
	VI	16.0	27.8	67	2.5	9.1	23.0	4.0	67.0
	VII	16.0	28.0	65	2.7	9.2	22.5	3.9	60.8
	VIII	15.4	29.8	60	2.3	11.1	22.9	3.9	43.4
	IX	10.6	21.9	70	2.5	5.3	12.9	1.9	70.9
Average		*12.8*	*25.2*	*65*	*2.7*	*8.3*	*19.8*	*3.1*	*346.8*

During the first year of research significant lack of rainfall occurred in July, when two irrigation intervals were added (80 mm) at deficit irrigation plots (a2) and three intervals (120 mm) at full irrigated plots (a3). In August there was excessive amount of rainfall (128% above average). This was similar to last year of research (2008), when same amount of irrigation water was added at two irrigation intervals in July and one in August in full irrigated plots (a3). Lack of rainfall during growth period of year 2007 was compensated with 120 mm (a2) and 200 mm (a3) of irrigation water. Averaged across years, crop evapotranspiration (ETc) during the growth period totalled 46.05 mm/dec (from initial to late stage). This represented 0.95 mm/day during initial stage, 2.03 mm/day during development stage, 4.22 mm/day during middle stage, and 2.49 mm/day during the late stage of soybean development. Daily crop evapotranspiration from initial to late stage are shown in Figure 2.

ETc values were significantly lower before the second decade of May (V4 stage), after what the increase was evident. Minimum Kc values occurred during initial (0.35) and development (0.6) or vegetative stages. Maximum Kc values (1) occurred during reproductive stage after what Kc declined (0.82). Deficit irrigated plots had ET value 7.7% (2006 and 2008) and 4.3% (2007) lower than full irrigated plots. Variations in seasonal ET as well as variation among irrigation treatments were previously reported by Payero et al. (2005). They found that small variation in seasonal ET among irrigation treatments for the same season where manly due to differences in irrigation frequency which affected the evaporation component of ET.

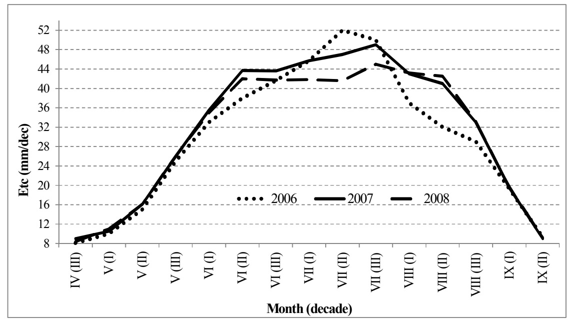

Figure 2. Monthly (decade) variation of crop evapotranspiration (ETc) in dry-land plots from 2006-2008

They also reported that the lowest ET were recorded in dry-land plots and the highest in full irrigated plots, which is in accordance to our results (Table 3). Averaged across years, grain yield of soybean at dry-land (a1) was 3.37 t ha^{-1} (Table 3). This is 4.42% lower compared to a2 irrigation regime (60-100% FWC) and 3.54% lower compared to full irrigated plots (a3). The highest yield at dry-land occurred in year 2008 (3.70 t ha^{-1}) with 346.8 mm of effective rainfall, favourable distribution of rainfall during growth period and the lowest radiation, as compared to the 2006 and 2007 growth periods.

Table 3. Yield (t ha^{-1}), evapotranspiration (ET) and irrigation water use efficiency (IWUE) of soybean for each irrigation regime, for years 2006-2008

Year	2006			2007			2008		
Specification	Y t ha^{-1}	ET (mm)	IWUE (kg m^{-3})	Y t ha^{-1}	ET (mm)	IWUE (kg m^{-3})	Y t ha^{-1}	ET (mm)	IWUE (kgm^{-3}
a1	2.94	445		3.48	478		3.70	458	
a2	3.16	482	2.7	3.52	535	0.3	3.97	469	3.3
a3	3.10	522	1.3	3.68	559	0.8	3.74	509	0.3
F value	57.216**			13.81*			81.005**		
$LSD_{0.05}$	44.27			83.42			47.01		
$_{0.01}$	60.65			114.27			64.39		

a1= dry-land; a2 = 60-100% field water capacity, a3 = 80-100% field water capacity; Y = yield (t ha^{-1}); ET = evapotranspiration (mm); IWUE = irrigation water use efficiency; *p<0.05; **p<0.01.

Irrigation regimes at deficit irrigated plots (a2) significantly increased (**p<0.01) grain yield in tested years, by 7.5% (2006), 1.15% (2007) and 7.3% (2008). Furthermore, irrigation regimes at full irrigated plots (a3) decreased grain yield in average years by 1.9% (2006) and 5.8% (2008), as compared to deficit irrigated plots (a2). However, in extremely warm and very dry growth period of year 2007, irrigation regime at full irrigated plots increased grain yield by 5.7% compared to control and by 4.6% compared to deficit irrigation regime. Irrigation water use efficiency (IWUE) of deficit irrigated plots was 2.7 kg m^{-3} (2006), 0.3 kg m^{-3} (2007) and 3.3 kg m^{-3} (2008). Furthermore, IWUE at full irrigated plots was 1.3 kg m^{-3} (2006), 0.8 kg m^{-3} (2007) and 0.3 kg m^{-3} (2008).

DISCUSSION

All three years were warmer as compared to long term average for this region (1961-1990). Rainfall during 2006 and 2008 was higher than average, although the distribution of rainfall during growth period was unfavourable (Figure 1), which is the main limiting factor for crop production in eastern Croatia (Josipović et al., 2010) and the main reason for applying supplemental irrigation practice. An occurrence of drought stress in tested years was during R3-R5 soybean growth stages, which corresponds to July-August period.

Soybean response to water deficit at different growth stages were reported by previous research of Huck et al., 1983; Foroud et al., 1993, Karam et al., 2005a,b. They found that water deficit during R3 (pod elongation) and R5 (grain enlargement) stages significantly reduced yield of soybean. The results of our studies show that grain yield of soybean is affected by periods of drought, which resulted in significantly lower yields at control plots (a1) in comparison to deficit and full irrigated plots. Schneekloth et al. (1991) compared the yield of soybean in dryland with deficit and full irrigated plots. They found that deficit irrigated treatments increased yield in compare to dry land and that yields in full irrigated plots were not significantly higher in compare to deficit irrigation. In our study in average growth season (2006 and 2008), adding water by keeping soil moisture content at 60-100% FWC was enough for soybean water needs, since the further increment of water ended with yield reduction by 2% (2006) and 6% (2008) as compared to deficit irrigated plots. As it seems, 80 mm of irrigation water in average climatic year is enough to compensate the lack of rainfall. Yield reduction at full irrigated plots may come as a result of nutrient leaching deeper in soil, especially nitrates. Since irrigation regime in our study was soil moisture dependent (not by growth stage of soybean), irrigation intervals at both regime (a2 and a3) in 2006 where in month July because the significant rainfall (31.9 mm) occurred in first decade of August followed by 21 mm in second and 69.7 mm in third decade, so there was no need to irrigate during that period. This was similar to year 2008, when same amount of irrigation water was added, yet only one interval in month August and rest of them in July (Table 2). During growth season 2007 irrigation water was distributed from June to August in order to compensate the lack of rainfall.

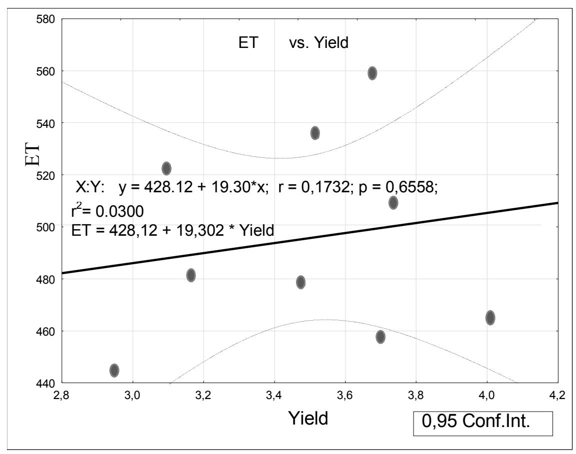

Figure 3. Relationship between yield and ET of soybean

As a result, there was yield increase at both irrigation regimes in compare to dryland (2% at a2 and 5.7% at a3). Small differences in yield of soybean grain in year 2007 across irrigation regimes came as result of good drought tolerance of tested variety. Across years the highest IWUE (3.3 kg m^{-3}) occurred at deficit irrigation plots in year 2008 (Table 3). Across irrigation regimes the highest IWUE at deficit irrigated plots in average years was for 1.4 (2006) and 3 kg m^{-3} (2008) higher than full irrigated plots. Karam et al. (2005$_b$) also studied the effect of different irrigation intervals on IWUE for soybean and found that deficit irrigated treatment had WUE value higher than full irrigated plots. Similar results were obtained by Comlekcioglu and Simsek (2011) and Sincik et al. (2008). Figure 3 shows weak but positive relationship (r = 0.17) between grain yield of soybean and ETo (at the 0.95 probability level for the 3 years). The relationship between evapotranspiration and yield of soybean has been the object of previous study by Pejić et al. (2012). They found that there was statistically significant linear relationship (at the 0.05 probability level for the 12 years) between evapotranspiration and yield of soybean (r=0.83).

CONCLUSION

The analysis of weather conditions showed need for supplement irrigation in sub-humid area of eastern Croatia. Since farmers in this area have enough water to meet seasonal water requirements of soybean (and other crops) supplemental irrigation can be a suitable measure to ensure stable yields. Soybean showed sensitivity to lack of rainfall during July and August, which corresponds to the pod initiation and grain enlargement stages (R3 to R5 stage). Higher water demands of soybean during reproductive stages in years with insufficient amount of rainfall and bad distribution during growth season can be compensated with properly induced irrigation. The result obtained in this study showed that grain yield was significantly increased by 7.4% ($p<0.01$) at deficit irrigated plots (60-100% FWC) in comparison to dry-farming in average years. By further irrigation at full irrigated plots (80-100% FWC) grain yield was decreased in comparison to the deficit irrigation. Opposite results were obtained in extremely warm and very dry growth season, when the maximum grain yield was obtained at fully irrigated plots (3.68 t ha^{-1}). Averaged across years, the highest IWUE was at deficit irrigated plots. IWUE at full irrigated plots in average years was decreased in comparison to deficit irrigated plots, meaning that irrigation at soil water content of 60-100% is sufficient for soybean needs in average climate years. The results from this study suggest that deficit irrigation can be used as tactical measure to ensure stable yield and best water use efficiency.

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