Agricultural Water Management 210 (2018) 224–231

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Effect of irrigation regime on yield, harvest index and water productivity of soybean grown under different precipitation conditions in a temperate environment

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ARTICLE INFO

Keywords:
Evapotranspiration
Agricultural water management
Glycine max (L.) Merr.
Water productivity
Yield composition

ABSTRACT

In temperate climatic regions, agricultural production depends on precipitation amount and its distribution during the growing season. A 3-year field study was conducted to investigate the effects of different irrigation regimes on yield parameters and water productivity of sprinkler-irrigated soybean [*Glycine max* (L.) Merr.], grown under wet, semi-dry and dry conditions in a temperate environment. Four irrigation levels were applied: full irrigation (I_{100}), 65% and 40% of full irrigation (I_{65} and I_{40}) and non-irrigated control (I_0). On average, the I_0 treatment resulted in the highest harvest index (HI) and I_{100} produced the lowest HI. A significant quadratic correlation between seed yield and crop water use was observed in dry and semi-dry year. The irrigation regime significantly influenced seed yield and water use. I_{65} treatment produced the highest seed yield (3.69 t ha^{-1}) and showed the highest water productivity (WP) (0.90 kg m^{-3}) and irrigation WP (1.08 kg m^{-3}). The present study indicated that irrigation is necessary for soybean cultivation in semi-dry and dry years i.e., when seasonal precipitation is lower than about 300 mm. In wet years, with a favourable amount and distribution of precipitation during the growing season, yields are similar to those achieved with irrigation and high ET values of soybean are attributable to increased evaporation.

1. Introduction

Temperate climate is characterized by large variability of weather parameters. At most places, agriculture depends on precipitation. Its amount and distribution vary from year to year and during growing seasons, which causes instability of production and reduces farmers' revenue. Therefore, supplemental irrigation is needed to increase and stabilise agricultural production especially during the precipitation scarce seasons.

Vojvodina is located in a temperate climatic zone of the Pannonian Plain, in the northern part of the Republic of Serbia. Agricultural production is prevalently rain-fed although it is one of priority economic sectors. Nevertheless, in this region, as in many similar regions around the world, the availability of freshwater resources for agricultural use has been decreasing due to climate change and increasing demand of other sectors.

Drought affects soybean growth and productivity in many parts of the world (Hatfield and Prueger, 2011; Steduto et al., 2012; Sentelhas et al., 2015). Water stress is principally harmful during flowering, seed setting and seed filling. The research findings indicated that limited, supplemental irrigation during the course of growing season or in a specific growth stage can significantly increase water productivity (WP) and soybean yields (Giménez et al., 2017; Jha et al., 2018). Response to irrigation depends on climate, rainfall pattern during growing season, soil properties, cultivar, agronomic practices, and experimental procedures.

Limited irrigation can result in substantial differentiation of crop productivity in various environments (Djaman et al., 2013). Akcay and Dagdelen (2016) reported that deficit irrigation may support the water saving irrigation programs under conditions of water scarcity. They stated that effective on-farm implementation of deficit irrigation might improve crop productivity when the data about crop yield response to water inputs are available. Knowledge of crop response to water stress over the growing season is useful also in crop growth modelling, enabling both improved prediction of crop performance in different situations and adoption of water saving management practices.

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https://doi.org/10.1016/j.agwat.2018.08.002
Received 4 April 2018; Received in revised form 1 August 2018; Accepted 3 August 2018
0378-3774/

In the Vojvodina region, soybean is one of the main field crops grown prevalently under rain-fed conditions. In the recent years, irrigation is becoming a common practice due to variable precipitation pattern and frequent drought caused by climate change. However, information is lacking on the impact of different irrigation levels on soybean yield and water productivity under different precipitation patterns. Consequently, the objective of this study is to compare the effects of three irrigation treatments and non-irrigated treatment on the growth, yield and water productivity of soybean grown under different precipitation conditions in a temperate climatic region. These data can be useful for soybean industry and the regional soybean growers to maximize the seed yield and productivity of water use through the selection of appropriate irrigation scheduling strategy.

2. Materials and methods

2.1. Site description and experiment set up

Field experiments were carried out during three growing seasons (2006, 2007, 2008) at Maize Research Institute “Zemun Polje”, Vojvodina, Serbia (44°52′ N, 20°20′ E, 81 m above sea level). The soil is classified as silty loam Calcaric Chernozem up to 0.60 m. Plant available water holding capacity to this depth (difference between –0.03 and –1.5 MPa) is 118 mm. The main chemical and physical characteristics of the soil in the study area are shown in Table 1.

The experimental area is characterized by a mild temperate climate with hot and dry summers. The long-term 30-years average annual precipitation is 638 mm with a notable inter- and intra-seasonal variability in amount and distribution pattern. The long-term average air temperature is 11.9 °C. The air temperature, precipitation, humidity and wind speed data were taken from Surčin Meteorological Station (Table 2). Rain-fed farming and occasional irrigations are the main production system in the study area.

The experiment was arranged in a randomized complete block design with four treatments and four replications. The following irrigation regimes were applied: I_{100}, I_{65}, I_{40}, and I_0, closely corresponding to no water deficiency treatment (full irrigation), 65% of full irrigation (35% deficit), 40% of full irrigation (60% deficit) and non-irrigated (rain-fed). In I_{100} treatment, the irrigation events replenished fully water depleted by evapotranspiration up to the field capacity (FC). In I_{40} and I_{65} treatments, the irrigation amounts referred to approximately 40% and 65% of I_{100} amount. The irrigation rates and timings were determined following the soil water content in the effective root zone depth (going up to 0.60 m). In all irrigated treatments, irrigation was practiced when soil water content reached approximately 50% of total available water (the difference in soil water storage between field capacity and wilting point). Full irrigation treatment includes the reservoir fulfillment up to water content at field capacity, whereas in the treatments I_{65} and I_{40}, 65% and 40% of full irrigation amounts were applied. The irrigation rates and time were determined depending on the soil water content in the effective root zone depth (to 0.60 m). Irrigation events were stopped two to three weeks before harvesting.

Irrigations were applied with the hand-move sprinkler irrigation system. Sprinklers heads with two nozzles mounted at 2.0 m were organized in 12 m × 12 m square grid. Operating pressure was about 3.50 MPa with a discharge of 0.41 l s^{-1}. Irrigation started on 11 July and 10 July in the first two seasons (2006 and 2007, respectively), and on 4 June in the third season. The last seasonal irrigations were applied in the third decade of July, and in the third and second decade of August in the first, second and third growing season, respectively.

Each experimental plot was designed 7.14 m long and 8.0 m wide (57.12 m^2). To minimize irrigation edge effects, the inter-plot space was 2.0 m.

Soybean cv. Nena (maturity group II) obtained from the Maize Research Institute “Zemun Polje” Company, was sown on 28 April 2006, 24 April 2007 and 6 May 2008 in 0.50 m-wide rows at a seeding rate of 4.45 seed m^{-2}. The crop was fertilized at the recommended rate, based on soil tests, with 450 kg ha^{-1} of NPK (15:15:15) before sowing, and a further nitrogen dose of 69 kg ha^{-1} was added as urea, when the plants were 25–30 cm in height. Weeds, pests and diseases were adequately controlled. Only the irrigation management differed between the treatments.

2.2. Crop and yield sampling

Seed yield was measured by harvesting an area of 5.0 m^2 per plot. Hand-harvest took place on 19, 18, and 15 October, respectively for 2006, 2007 and 2008. Seed yield was normalized for 13% seed water concentration. Harvest index was determined as seed yield divided by the total aboveground biomass after drying the samples at 65 °C.

2.3. Soil water and crop evapotranspiration

Soil water content was measured periodically throughout the growing seasons using gravimetrical method at different depth, starting at 0.10-m at sowing and going down to 0.60 m at flowering and hence after. The measurements were based on the conventional oven-dry mass. Gravimetrical water content was converted to volumetric water content after multiplying it by the bulk density. Soil bulk density was measured at the beginning of each crop season at 0.10 m interval depths up to 0.60 m.

Actual crop evapotranspiration or total water consumption (ETa, mm) of each plot was calculated according to Sincik et al. (2008):

$$ETa = P + I + C_r - D_p - R_f \pm \Delta S \quad (1)$$

where P is the rainfall in the growth period (mm), I is the amount of net irrigation water applied to individual plots (mm), Cr is capillary rise of water from below the root zone (mm), Rf is the surface runoff (mm), Dp is the water lost through deep percolation (mm), and ΔS is the cumulative change in the soil water storage between planting and harvest within the effective crop root zone (mm). Irrigation scheduling was based on the soil water balance method and gravimetric soil water content measurements. In Eq. (1) *Cr* was assumed to be zero, because the water table was at 80 m depth. Deep percolation was ignored because soil water content measurements showed that no water percolated below 100 cm depth. The run-off and run-on was also assumed to

Table 1
Physical and chemical properties of the Calcaric Chernozem 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)	$CaCO_3$ (%)	Organic matter (%)	Available nitrogen (mg kg^{-1})	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})
	Clay[a]	Silt	Sand										
0–20	28.4	67.3	4.3	1.21	31.1	15.0	16.2	7.73	4.3	2.99	27.5	660	250
20–40	26.7	69.2	4.2	1.33	37.0	15.1	21.9	7.77	5.6	2.92	39.9	380	200
40–60	26.6	68.3	5.2	1.28	37.5	14.9	22.6	7.92	22.7	1.57	21.1	85	80

[a]Clay < 0.002 mm, Silt 0.05–0.002 mm, Sand 2.00–0.05 mm.