doi: 10.17221/673/2016-PSE

Yield and chemical composition of soybean seed under different irrigation regimes in the Vojvodina region

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ABSTRACT

Kresović B., Gajic B.A., Tapanarova A., Dugalić G. (2017): Yield and chemical composition of soybean seed under different irrigation regimes in the Vojvodina region. Plant Soil Environ., 63: 34–39.

The goal of the present research is to determine an effective sprinkler irrigation strategy for soybean [*Glycine max* (L.) Merr.] in temperate climate conditions, in order to maximize yields and seed quality. A three-year field experiment with four different irrigation treatments was conducted on Calcic Chernozem in the Vojvodina region of Serbia. The irrigation regimes included: no irrigation; full irrigation (I_{100}); and two deficit irrigation treatments – 65% of I_{100} (I_{65}) and 40% of I_{100}. The irrigation treatments generally had a statistically significant effect on the increase of soybean yield and protein content. Irrigation did not have a significant effect on the oil content. In general, irrigation increased K, P, Mg, Mn, Cu, Zn and B concentrations and decreased Ca and Fe concentrations in soybean seed. The results show that irrigation with the largest amount of water (treatment I_{100}) provided no potential benefit in terms of soybean yield and chemical composition. Treatment I_{65}, which exhibited the most favourable watering conditions, is the best choice to maximize yield and ensure a good chemical composition of soybean under these agroecological conditions.

Keywords: water deficit; nutritional composition; micronutrient; macroelement; mineral content

In Vojvodina, like in other parts of Serbia, soybean is mostly rainfed. As such, soybean yields vary from year to year and are generally low in dry years. Soybean irrigation leads to yield increase and less variation among years in arid, semi-arid, humid and sub-humid regions (Al-Tawaha et al. 2007, Sincik et al. 2008). Irrigation also affects the chemical composition of soybean (Kumawat et al. 2000, Bennett et al. 2004) including protein, oil, sugar and minerals (Bellaloui et al. 2015). Soybean quality depends on the oil and protein content, as it is the main source of high-quality protein and oil (Grieshop and Fahey 2001). More food of greater nutritional value, such as soy milk and tofu, is produced from soybeans with higher protein content (de Moraes et al. 2006). Users of these products prefer less oil and more protein (Kumar et al. 2006). Soybean is an important source of macro- and microminerals, such as P, K, Ca, Mn, Zn, Fe and B, which are indispensable in human food. A lack of these elements can lead to human malnutrition and health issues (Bouis 2003, Lu et al. 2008). As such, soybean quality improvement is extremely important for enhancing human and livestock nutrition (Bellaloui et al. 2010). According to available literature on the subject, the mineral

Supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Projects No. III 43009 and TR 31037.

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composition of irrigated soybean has not been extensively researched.

The correlation among the chemical composition of soybean and water stress is still debated. Many researchers determined that the amount of protein decreases with soil water deficit (Specht et al. 2001, Boydak et al. 2002, Carrera et al. 2009). Contrarily, Kumar et al. (2006) and Rotundo and Westgate (2010) found that the protein content increases with increasing water deficit. Some researchers report increasing oil content with water deficit, whereas others indicate that it decreases with soil water deficit (Specht et al. 2001, Rotundo and Westgate 2010). Little information is available about the effect of different irrigation treatments on the chemical composition of soybean, and in particular, its mineral composition, in temperate climate conditions such as those that prevail in the study area. The present research aims at determining the effect of different irrigation treatments on soybean yield and chemical composition in the ecological conditions that exist in Vojvodina. Knowledge of the effect of different irrigation treatments will be useful to soybean farmers in this region of Serbia as well as in neighbouring countries. The effects of irrigation and local climate conditions on the chemical composition of soybean are also highly relevant to food industry.

MATERIAL AND METHODS

Study area location and climate. The three-year study (2012–2014) was conducted on an irrigated experimental field of the Maize Research Institute of Zemun Polje, Serbia (44°52'N, 20°20'E), on Calcic Chernozem. The climate is temperate (warm and dry summers); the year average precipitation total is 638 mm and the year average air temperature 11.9°C. Table 1 shows mean monthly precipitation levels and temperatures for all three growing seasons.

Experimental setup. The experiment focused on four irrigation treatments: full irrigation (I_{100}); I_{65} – 65% of I_{100}; I_{40} – 40% of I_{100}; and no irrigation (I_0). The amount of water applied in full irrigation treatment was calculated as the amount of water necessary to replenish to the field capacity in 0–60 cm soil depth. The experiment was set up according to a randomized block design, with four replications. In all three study years, the soybean cultivar used was Nena (II MG), selected at the Maize Research Institute of Zemun Polje. The seeds were sown on 28, 19 April and 6 May in 2012, 2013 and 2014, respectively. Each experimental plot comprised of 16 rows, 7.14 m long. The space among the rows was 0.5 m and the sowing density was 44.5 seeds per m^2. The experimental field was irrigated by a manually-movable sprinkler system. Irrigation was initiated when the soil moisture in treatment I_{100} at a depth of 60 cm was roughly 50% of the accessible water. Amounts of irrigation water applied to treatments during the soybean growing period are presented in Table 2.

Soybean crop was harvested on 19, 18 and 15 October in 2012, 2013 and 2014, respectively. The yield of each plot was determined by manual counting in two central consecutive rows, 5 m long, and adjusted to a moisture content of 13%. The protein and oil content were determined by

Table 1. Mean monthly air temperature and cumulative monthly rainfall of years 2012 to 2014, Zemun Polje, Serbia

Month	Mean air temperature (°C)			Cumulative monthly rainfall (mm)		
	2012	2013	2014	2012	2013	2014
April	13.4 (+1.3)	12.2 (+0.2)	13.2 (+1.2)	27.3 (–32.4)	93.1 (+33.4)	31.1 (–28.6)
May	18.3 (+1.1)	15.8 (–1.4)	19.0 (+1.6)	39.7 (–15.9)	33.3 (–22.3)	42.0 (–13.6)
June	22.3 (+2.2)	18.8 (–1.3)	22.5 (+2.4)	36.3 (–59.1)	143.6 (+48.2)	63.0 (–32.4)
July	22.6 (+0.8)	22.8 (+1.0)	23.9 (+2.1)	46.2 (–10.5)	27.3 (–29.4)	18.7 (–38.0)
August	22.8 (+0.6)	19.6 (–2.6)	23.7 (+1.5)	19.7 (–42.1)	109.0 (+47.2)	51.6 (–10.2)
September	16.6 (–1.4)	18.6 (+0.5)	15.0 (–2.9)	55.4 (+0.4)	10.8 (–44.2)	73.0 (+18.0)
Seasonal mean/total	19.3 (+0.7)	17.9 (–0.7)	19.5 (+0.9)	225 (–159.5)	417.1 (+33.1)	279 (–104.7)

Values in parentheses represent divergence from normal (20-year average)

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Table 2. Seasonal irrigation supply, sum of irrigation and rain during the growing season, seed yield of soybean, protein content and oil content under different irrigation treatments

Year	Irrigation treatment	Irrigation (mm)	Irrigation + rain from seeding to harvest (mm)	Seed yield (t/ha)	Protein content (g/kg)	Oil content (g/kg)
2012	I_0	0	417	1.63^d	370.1^b	200.6^a
	I_{40}	94	417	2.55^c	370.5^b	200.4^a
	I_{65}	153	447	3.21^a	391.6^a	201.7^a
	I_{100}	235	477	2.69^b	365.3^c	201.9^a
2013	I_0	0	279	3.26^c	390.5^a	203.2^a
	I_{40}	0	329	3.27^c	383.0^b	203.9^a
	I_{65}	39	359	4.27^a	383.0^b	201.5^a
	I_{100}	60	414	3.77^b	378.5^c	201.5^a
2014	I_0	0	224	2.88^c	397.1^b	197.4^a
	I_{40}	54	319	3.09^b	405.4^a	194.8^a
	I_{65}	88	384	3.60^a	406.7^a	194.5^a
	I_{100}	135	459	3.50^a	393.5^c	197.3^a
2012–2014	I_0	0	307	2.59^d	385.9^b	200.4
	I_{40}	49	355	2.97^c	386.3^b	199.7^a
	I_{65}	93	397	3.69^a	393.8^a	199.2^a
	I_{100}	143	450	3.32^b	379.1^c	200.2^a

Means in the same column with different letters within each year are significantly different at the $P < 0.05$. I_0 – no irrigation; I_{40} – 40%; I_{65} – 65% of I_{100}; I_{100} – full irrigation

the NIR spectroscopy (Instalab 700 NIR Grain Analyzer, DICKEY-john, Auburn, USA). The concentrations of Ca, Mg, Fe, Mn, Cu and Zn were determined by atomic absorption spectrometry (Varian Spectra AA 220, Palo Alto, USA). Phosphorus was determined by colorimetry and potassium by flame photometry.

Statistical analysis. The experimental data were statistically analysed by ANOVA, using the SPSS software (version 20, Chicago, USA). Fisher's *LSD* test was applied to determine significant differences among treatments with α = 0.05.

RESULTS AND DISCUSSION

Seed yield. In this research, the response of soybean yields to the irrigation treatments varied from year to year (Table 2). As expected, all irrigation treatments in all three years resulted in significantly higher ($P < 0.05$) seed yields than the rainfed treatment (Table 2). In all three study years, the yield under treatment I_{65} was significantly higher than under the other two irrigation treatments. The soybean yield under full irrigation (I_{100}) was 0.35 and 0.73 t/ha higher, on average, than under I_{40} and I_0, respectively, but 0.37 t/ha lower than that under treatment I_{65}. The reasons for this are unknown but according to Campbell and Phene (1977) too much moisture tends to reduce O_2 concentrations in the soil and thus lower crop yields. Al-Tawaha et al. (2007) studied the effects of different irrigation levels on soybean yields, oil and protein content, and other major agronomic characteristics in Québec, Canada. They found that irrigation treatments generally resulted in higher yields, compared to the rainfed treatment that served as a control.

Protein and oil content. In this study the protein content of soybean exhibited irregular variation from I_{40} to I_{100} (Table 2). Treatment I_{65}, which achieved the highest yields, had the highest protein content, followed by irrigation treatments I_{40} and I_{100}, meaning that irrigation increased the protein content. The rainfed treatment (I_0) produced, on average, a 2% lower protein content than full irrigation (I_{100}), which suggested that maintaining a high level of soil moisture during the growing season was harmful to protein accumulation in soybean in those agroecological conditions. Dornbos and Mullen (1992) also determined that severe drought can increase the protein content. A higher content was achieved in

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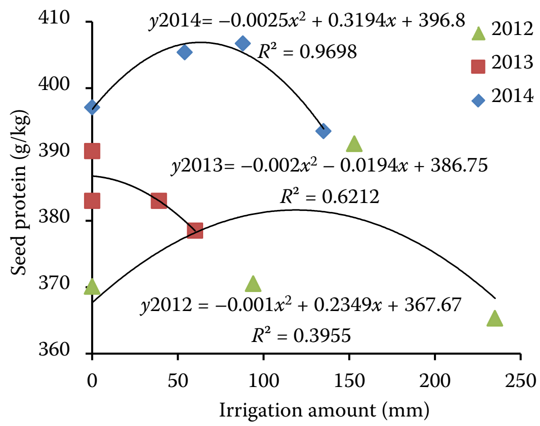

Figure 1. The relationship among the amount of irrigation water and soybean seed protein content

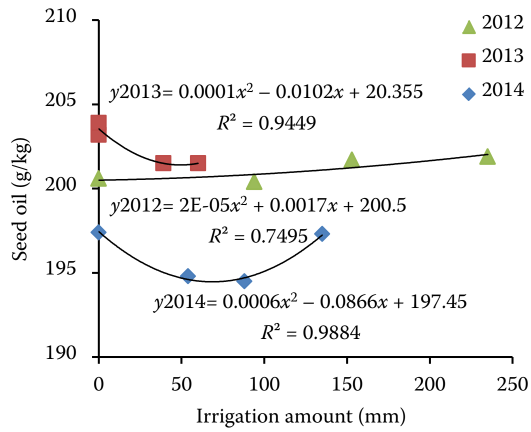

Figure 2. The relationship among the amount of irrigation water and soybean seed oil content

the growing season of 2014 than in 2013 and 2012. These differences might be associated with higher air temperatures during seed-filling period in 2014, since elevated temperatures can increase the protein content of soybean (Kumar et al. 2006).

Contrary to the results reported herein, Al-Tawaha et al. (2007) established that irrigation levels had no effect on the protein content of soybean. The present results also differ from those of other studies (Liu et al. 2004, Candogan et al. 2013) that reported a decrease in protein content as soybean yield was maximized by irrigation.

A statistically significant ($P < 0.05$) polynomial relationship among the seed protein content and the irrigation water was observed (Figure 1). Contrary to this research, Kirnak et al. (2010) established a power function among the amount of water used during the soybean growing season and the protein content of soybean grown under semi-arid conditions in Turkey.

The results of this research indicate that irrigation treatments did not have a significant effect on the oil content, which is an important qualitative component of soybean. On average, treatments

Table 3. The concentrations of macrominerals in soybean seed under different irrigation treatments (g/kg)

Year	Irrigation treatment	P	K	Ca	Mg
2012	I_0	16.40[d]	9.20[d]	3.00[a]	1.81[d]
	I_{40}	16.90[c]	10.01[a]	2.67[c]	1.89[c]
	I_{65}	17.45[a]	9.60[c]	2.83[b]	2.35[a]
	I_{100}	16.99[b]	9.80[b]	2.19[d]	2.15[b]
2013	I_0	17.25[b]	9.60[d]	2.75[a]	1.96[c]
	I_{40}	16.60[c]	10.20[a]	2.45[b]	1.97[c]
	I_{65}	17.45[a]	9.79[c]	2.47[b]	2.25[a]
	I_{100}	17.25[b]	10.02[b]	2.31[c]	2.02[b]
2014	I_0	15.75[d]	9.03[c]	3.13[a]	1.74[d]
	I_{40}	16.90[c]	10.04[a]	2.46[c]	1.97[c]
	I_{65}	17.25[a]	9.00[c]	2.66[b]	2.56[a]
	I_{100}	17.10[b]	9.81[b]	2.33[d]	2.13[b]
2012–2014	I_0	16.47[d]	9.28[d]	2.96[a]	1.84[d]
	I_{40}	16.80[c]	10.08[a]	2.53[c]	1.94[c]
	I_{65}	17.38[a]	9.46[c]	2.65[b]	2.39[a]
	I_{100}	17.11[b]	9.88[b]	2.28[d]	2.10[b]

Means in the same column with different letters within each year are significantly different at the $P < 0.05$. I_0 – no irrigation; I_{40} – 40%; I_{65} – 65% of I_{100}; I_{100} – full irrigation

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I_{100} and I_0 registered the highest oil content in all study years. Similar to the present research, Al-Tawaha et al. (2007) found that irrigation had no effect on the oil content of soybean, regardless of the amount of irrigation water applied. By contrast, Kirnak et al. (2010) examined the effect of different drip irrigation rates on soybean yield and quality over two years and recorded the highest oil content of rainfed soybean in both years.

The results of statistical regression analysis indicated a polynomial relation among the oil content of soybean and the amount of irrigation water used during the growing season (Figure 2). Contrary to this research, Kirnak et al. (2010) established an inverse linear relation among the seasonal water demand of soybean.

Mineral composition. The results of the present research show that the irrigation treatments had a significant ($P < 0.05$) effect on the concentrations of the studied macrominerals (Table 3). The concentrations of K, P and Mg were much higher under irrigation treatments than in rainfed conditions. Treatment I_{65} registered the highest P and Mg concentrations and treatment I_{40} the highest concentration of K. Consequently, large amounts of water added by irrigation can reduce soybean seed P and Mg concentrations to a considerable extent. Prior research has shown that access to low-mobility minerals, such as K and P, decreases in cold and humid soil conditions (Barber 1971). Under all irrigation treatments, the Ca concentration of soybean was much lower than that of rainfed soybean. The treatment that added the most water (I_{100}) resulted in a much lower Ca concentration than treatments I_{65} and I_{40}.

The irrigation treatments also had a major impact on the concentrations of microminerals in all three years (Table 4). In the present research, irrigation significantly ($P < 0.05$) decreased Fe concentrations. On average, the highest concentration was recorded under rainfed conditions and the lowest under treatment I_{40}. No significant differences were noted in Fe concentrations among treatments I_{100} and I_{65}. Irrigation treatments I_{100} and I_{65} resulted in higher Mn and Cu concentrations than I_0 and I_{40}. The rainfed treatment recorded the lowest Cu concentration. No statistically significant differences were observed in Mn concentrations among the rainfed treatment and treatment I_{40}. Also, there were no large differences in Mn and Cu concentrations among treatments I_{100} and I_{65}. Irrigation treatment I_{65} resulted in a much higher Zn concentration than the rainfed and other irrigation treatments. The rainfed treatment and irrigation treatments I_{100} and I_{40} showed no notable differences in Zn concentrations of soybean. Our

Table 4. The concentrations of microminerals in soybean seed under different irrigation treatments (mg/kg)

Year	Irrigation treatment	Fe	Mn	Cu	Zn
2012	I_0	65.46^a	33.90^b	10.76^c	34.94^b
	I_{40}	57.04^c	34.95^b	11.93^b	35.88^b
	I_{65}	59.72^b	36.23^a	14.58^a	37.12^a
	I_{100}	61.36^b	36.78^a	13.32^a	35.56^b
2013	I_0	65.24^a	35.53^b	12.73^c	37.08^b
	I_{40}	57.68^c	36.83^b	13.65^b	37.40^b
	I_{65}	63.32^b	39.32^a	15.65^a	38.60^a
	I_{100}	62.48^b	38.59^a	15.23^a	36.98^b
2014	I_0	65.68^a	32.12^b	10.73^c	35.28^b
	I_{40}	60.20^c	33.80^b	12.17^b	35.08^b
	I_{65}	63.48^b	37.19^a	14.95^a	36.49^a
	I_{100}	62.34^b	36.92^a	14.50^a	35.80^b
2012–2014	I_0	65.46^a	33.85^b	11.41^b	35.77^b
	I_{40}	58.31^c	35.19^b	12.58^b	36.12^b
	I_{65}	62.17^b	37.58^a	15.06^a	37.40^a
	I_{100}	62.06^b	37.43^a	14.35^a	36.11^b

Means in the same column with different letters within each year are significantly different at the $P < 0.05$. I_0 – no irrigation; I_{40} – 40%; I_{65} – 65% of I_{100}; I_{100} – full irrigation

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results indicate that the concentrations of Zn in soybean seed varied less than concentrations Fe, Mn and Cu.

Based on the results of our 3-year field experiments it can be concluded that the response of yields and seed composition of soybean depends on the irrigation level and growing season. The results show that irrigation with the largest amount of water (treatment I_{100}) provided no potential benefit in terms of soybean yield and chemical composition. Based on the results of this study, treatment I_{65} is the recommended strategy for stable and high yields of soybean, with a good chemical composition, under the agroecological conditions in Vojvodina and neighbouring countries.

REFERENCES

Al-Tawaha A.M., Seguin P., Smith D.L., Bonnell R.B. (2007): Irrigation level affects isoflavone concentrations of early maturing soya bean cultivars. Journal of Agronomy and Crop Science, 193: 238–246.

Barber S.A. (1971): Effect of tillage practice on corn (*Zea mays* L.) root distribution and morphology. Agronomy Journal, 63: 724–726.

Bellaloui N., Bruns H.A., Abbas H.K., Mengistu A., Fisher D.K., Reddy K.N. (2015): Agricultural practices altered soybean seed protein, oil, fatty acids, sugars, and minerals in the Midsouth USA. Frontiers in Plant Science, 6: 31.

Bellaloui N., Bruns H.A., Gillen A.M., Abbas H.K., Zablotowicz R.M., Mengistu A., Paris R.L. (2010): Soybean seed protein, oil, fatty acids, and mineral composition as influenced by soybean-corn rotation. Agricultural Sciences, 1: 102–109.

Bennett J.O., Yu O., Heatherly L.G., Krishnan H.B. (2004): Accumulation of genistein and daidzein, soybean isoflavones implicated in promoting human health, is significantly elevated by irrigation. Journal of Agricultural and Food Chemistry, 52: 7574–7579.

Bouis H.E. (2003): Micronutrient fortification of plants through plant breeding: Can it improve nutrition in man at low cost? Proceedings of the Nutrition Society, 62: 403–411.

Boydak E., Alpaslan M., Hayta M., Gercek S., Simsek M. (2002): Seed composition of soybeans grown in the Harran region of Turkey as affected by row spacing and irrigation. Journal of Agricultural and Food Chemistry, 50: 4718–4720.

Campbell R.B., Phene C.J. (1977): Tillage, matric potential, oxygen and millet yield relations in a layered soil. Transactions of the American Society of Agricultural Engineers, 20: 271–275.

Candogan B.N., Sincik M., Buyukcangaz H., Demirtas C., Goksoy A.T., Yazgan S. (2013): Yield, quality and crop water stress index relationships for deficit-irrigated soybean [*Glycine max* (L.) Merr.] in sub-humid climatic conditions. Agricultural Water Management, 118: 113–121.

Carrera C., Martínez M.J., Dardanelli J., Balzarini M. (2009): Water deficit effect on the relationship between temperature during the seed fill period and soybean seed oil and protein concentrations. Crop Science, 49: 990–998.

de Moraes R.M.A., José I.C., Ramos F.G., de Barros E.G., Moreira M.A. (2006): Biochemical characterization of high protein soybean lines. Pesquisa Agropecuária Brasileira, Brasília, 41: 725–729.

Dornbos D.L.Jr., Mullen R.E. (1992): Soybean seed protein and oil contents and fatty acid composition adjustments by drought and temperature. Journal of the American Oil Chemists Society, 69: 228–231.

Grieshop C.M., Fahey G.C.Jr. (2001): Comparison of quality characteristics of soybeans from Brazil, China, and the United States. Journal of Agricultural and Food Chemistry, 49: 2669–2673.

Kirnak H., Dogan E., Türkoğlu H. (2010): Effect of drip irrigation intensity on soybean seed yield and quality in the semi arid Harran plain, Turkey. Spanish Journal of Agricultural Research, 8: 1208–1217.

Kumar V., Rani A., Solanki S., Hussain S.M. (2006): Influence of growing environment on the biochemical composition and physical characteristics of soybean seed. Journal of Food Composition and Analysis, 19: 188–195.

Kumawat S.M., Dhakar L.L., Maliwal P.L. (2000): Effect of irrigation regimes and nitrogen on yield, oil content and nutrient uptake of soybean (*Glycine max*). Indian Journal of Agronomy, 45: 361–366.

Liu X.B., Herbert S.J., Jin J., Zhang Q.Y., Wang G.H. (2004): Responses of photosynthetic rates and yield/quality of main crops to irrigation and manure application in the black soil area of Northeast China. Plant and Soil, 261: 55–60.

Lu K.Y., Li L.Z., Zheng X.F., Zhang Z.H., Mou T.M., Hu Z.L. (2008): Quantitative trait loci controlling Cu, Ca, Zn, Mn and Fe content in rice grains. Journal of Genetics, 87: 305–310.

Rotundo J.L., Westgate M.E. (2010): Rate and duration of seed component accumulation in water-stressed soybean. Crop Science, 50: 676–684.

Sincik M., Candogan B.N., Demirtas C., Büyükacangaz H., Yazgan S., Göksoy A.T. (2008): Deficit irrigation of soybean [*Glycine max* (L.) Merr.] in a sub-humid climate. Journal of Agronomy and Crop Science, 194: 200–205.

Specht J.E., Chase K., Macrander M., Graef G.L., Chung J., Markwell J.P., Germann M., Orf J.H., Lark K.G. (2001): Soybean response to water: A QTL analysis of drought tolerance. Crop Science, 41: 493–509.

Received on October 16, 2016
Accepted on December 10, 2016