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Source / Izvornik: **Poljoprivreda, 2022, 28, 32 - 38**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.18047/poljo.28.1.5

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Odnos komponenenata prinosa i prinosa zrna soje (*Glycine max* L. Merr.) u uvjetima navodnjavanja

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Poljoprivreda / Agriculture

ISSN: 1848-8080 (Online)
ISSN: 1330-7142 (Print)

https://doi.org/10.18047/poljo.28.1.5

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ISSN 1330-7142
UDK=633.34:631.64
https://doi.org/10.18047/poljo.28.1.5

RELATIONSHIP BETWEEN THE SOYBEAN (*Glycine max* L. Merr.) YIELD COMPONENTS AND THE SEED YIELD UNDER IRRIGATION CONDITIONS

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Original scientific paper
Izvorni znanstveni članak

SUMMARY

The study presents the results of a three-year experiment (2013–2015) that was carried out to determine a relationship between the soybean yield components and the seed yield under different irrigation treatments. The results indicated that the study year had the greatest effect on the number of nodes per plant (NNP), while an interaction between the irrigation and experiment year was also statistically significant. The highest average NNP was observed in 2015, being 33% higher when compared to the year 2014. The highest number of seeds per plant (NSP) was observed in 2015, being 20% and 31% higher when compared to 2013 and 2014. An abundant irrigation resulted in the highest NSP when compared to a rational and control treatment. Irrigation, study year, and their interaction did not have a statistically significant effect on the thousand seed weight (TSW) (g), but the lowest average TSW (g) was obtained in the control treatment of each study year. Regression models pertaining to the seed yield prediction in the control treatment and rational irrigation were not statistically significant. However, in the abundant irrigation, the regression model based on the TSW (g), NNP, and the NSP as the predictors provided for a statistically significant model seed yield prediction, but only the NSP was identified as a highly significant seed yield predictor.

Keywords: soybean, irrigation, yield components, correlation, yield estimation

INTRODUCTION

Soybean (*Glycine max* L. Merr.) is a highly profitable crop, with a global production being constantly increased in recent years. Due to the protein, oil, and phytochemical source substance quality, this legume is gaining a heightened importance worldwide. About a third of the world's vegetable oil production is obtained from soybeans (FAOSTAT, 2021). It is highly important in human nutrition, since it satisfies 30% of the protein needs, being a source of nutritional compounds with many different medical benefits (Cober, 2009). Soybean is also considered to be the most widespread natural source of isoflavones in human and animal nutrition, and its scientific value and diversity of use have been confirmed by continuous scientific and technological development. Its seed contains quality proteins, unsaturated fatty acids, fiber, vitamins and minerals. Commercial varieties in seed, depending on the growing conditions, contain approximately 40% of protein, 20–22% of oil, 34% of carbohydrates and approximately 5% of minerals, as well as vitamins A, B-complex, D, E and K (Vratarić and Sudarić, 2008). Due to the quality of proteins and high oil content, it is a more suitable substitute for meat than the majority of other crops (Sudarić, 2011). An increase in the soybean usage in domestic animal feed, processing industry, and human nutrition also increases a necessity for higher yield and its quality (Umburanas, 2018). According to the FAO data, soybean cultivation areas in Croatia in the past

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have averagely amounted to approximately 82,000 ha five years, and the total seed production amounts to 244,000 tons (FAOSTAT, 2021). Climate change has the greatest impact on the plants due to their sessile lifestyle, causing them to continuously be subjected to potential stressors that threaten their survival due to a prolonged exposure (Claeys and Inze, 2013). As the frequency of adverse weather events has increased over the past 20 years, continuous and intensive research is necessary to create the stable European varieties of high-quality seeds that would become an integral part of conservation agriculture (Jug et al., 2018). In order to maintain the positive trends and rebalance the soybean supply sources in the future, production must be accompanied by continuous and intensive research in order to achieve a better quality and higher yields. Due to the increasing soybean demand, there is a necessity of sustainable solutions to combat the loss of its productivity caused by water stress (Prudent et al., 2015). Available irrigation water reserves tend to be annually decreased on a global scale, which indicates that the food production in the forthcoming years will likely be carried out in the conditions of a water deficit. Therefore, a rational water resources and food management is necessary, since the lack of water throughout the growing season exerts a significant effect on the seed yield and its quality (Fereres et al., 2003; Ries et al., 2012). Soybean has a great ability to compensate the yield, so that a single yield component, decreased by the stress, can subsequently be replaced by an increase in the other component (Basić, 2006). Yield prediction using its components has increasingly become more applicable in the agricultural practice of farmers whose product is cultivated for commercial purposes (Wei and Molin, 2020). The number of seeds per plant is determined by the number of pods per plant, as well as by the number of seeds per pod, and mostly depends on the sufficient amounts of water during flowering, seed formation, and seed filling stage (Kresović, 2016). The aim of this study was to compare the effectiveness of irrigation rates on the soybean yield components and the seed yield on a hydromeliorated hypogley under the agroecological conditions of eastern Croatia.

MATERIALS AND METHODS

The research was conducted on the agrarian area of the Agricultural Institute Osijek in the period from 2013 to 2015. The climate indicators of the Croatian Meteorological and Hydrological Service (CMHS, 2017) in the three study years differed mutually and in relation to the long-term average (1981–2010; see Table 1). During the 2013 and 2014 soybean growth period, more precipitation fell than it was the case concerning the long-term average, that is, 30.0 mm and 132.7 mm, respectively. In 2015, only 315.9 mm of precipitation was registered, which is 74.7 mm below the long-term average. Irrigation was performed in three treatments: a control treatment (I1), containing no irrigation besides the natural precipitation conditions; rational irrigation (I2), under which the soil water content was maintained between 60% to 100% of retention water capacity (RWC); and an abundant irrigation (I3), under which the soil water content was maintained between 80% to 100% of the RWC. Groundwater levels were measured twice a week in a well located 100 m away from the study area to determine the groundwater impact on the soybean yield.

Table 1. Total monthly precipitation during the 2013–2015 soybean vegetation and a long-term average for the Osijek Airport's meteorological station Service (CMHS, 2017)

Tablica 1. Mjesečna količina oborina tijekom vegetacije soje 2013. - 2015. i višegodišnji prosjek za meteorološku postaju Zračna luka Osijek Service (CMHS, 2017)

Month / **Mjesec**	Total monthly precipitation during the study and long-term average (mm) / *Mjesečna količina oborina tijekom istraživanja i višegodišnji prosjek (mm)*			
	2013	2014	2015	1981–2010
April / **Travanj**	44.9	81.3	12.9	52.4
May / **Svibanj**	119.0	161.4	113.4	63.9
June / **Lipanj**	63.6	91.0	17.1	87.1
July / **Srpanj**	36.5	66.4	25.6	56.0
August / **Kolovoz**	32.9	54.3	105.8	68.3
September / **Rujan**	123.7	68.9	41.1	62.9
Total (April–September) / *Ukupno (travanj–rujan)*	420.6	523.3	315.9	390.6

Irrigation was performed from the sowing to the seed filling stage using a self-propelled trailed sprayer (typhoon), based on an irrigation rate calculated according to the soil water properties. The average working pressure at the typhoon inlet amounted to 5-7 kPa and 3-4 kPa at the sprinkler nozzle. The sprayer was located on a mobile "trolley" and spraying was connected with a quick-connect coupling for a PE pipe with the diameter of 50 mm and the length of 150 m. The desired irrigation rate was achieved by adjusting the sprayer movement speed. At the pipe's wall outlet, a water meter was mounted to control the irrigation rate. The irrigation water was pumped from a 37 m deep well, with a yield of about 7.0 l s^{-1}, and the optimal pumping values were about 5.5 l s^{-1}. An electric depth pump with a 5.5 kW power set at a depth of 19 m was used to pump the water. The irrigation start moment was defined according to the present soil moisture, determined by the electrometric method using a watermark device. The sensors were placed at two soil depths (of 20 and 30 cm, respectively), and a two-reading average was taken as an irrigation starting point indicator. The sensor values ranged from 0–200 cbar, where the 0 value represented 100% of the soil RWC, and the value of 200 cbar represented the soil RWC at which the plants wither. In the three years of study, the precipitation amount and distribution during the soybean growth period (from April to September) were significantly different and affected the dynamics of the soil water content. The irrigation rates number and schedule differed according to these variabilities. Also, the soil water content dynamics influenced the irrigation rates in the variants I2 and I3. The variants of soil water content maintenance amounting to 60–100% RWC (I2) and 80–100% RWC (I3) were applied in a variable irrigation rate number according to the soil water content dynamics in each variant. During the growing season, a total of 105 mm of rainwater was added in three rates in the I2 variant, and a total of 210 mm in six rates in the I3 variant. In a full technological maturity, a soybean seed yield sampling and a yield component sampling were performed. Prior to the harvest, 12 average plants (10 were analyzed and two were a reserve) were taken from each plot to determine the yield components. Harvesting was performed by a *Wintersteiger* combine harvester. The obtained seed amount was weighed for each plot and converted into kg ha^{-1}. The seed yield data collection method was thoroughly explained by Galić Subašić et al. (2017). The yield components included the number of nodes per plant (NNP), the number of seeds per plant (NSP), and the thousand seed weight (TSW) (g). The NNP included all fertile and infertile nodes on the plant. The NSP included all healthy, diseased, or scarce seeds on the plant. The TSW (g) was expressed in g and determined by the Contador automatic counter and sample weighing. The study was conducted using four soybean varieties: *Lucija* (a very early variety), *Tena* (a moderately early variety), *Ika* (a moderately early variety) and *Vita* (an early variety), created at the Agricultural Institute Osijek. The seed yield, the number of nodes per plant, the number of seeds per plant and the thousand seed weight obtained across the used varieties were averaged for the purposes of this analysis. Statistical analysis was performed using the SAS and the *Microsoft Excel* software. Two factorial analyses of variance were used to test the effect of treatments on the examined traits. Statistically significant differences between the mean values of the examined treatments were determined by the least significant differences (LSD) test ($p < 0.01$), calculated for all observed variables, and the strength and direction of a relationship between them were examined using a correlation coefficient (r). Furthermore, statistical analyses of single correlation, regression, and multiple correlation and regression were performed.

RESULTS AND DISCUSSION

The year had the strongest effect on the NNP, but other treatments, like the irrigation and its study year (I x Y) interaction, also had a statistically significant effect on the examined trait (Table 2). The highest average NNP was observed in 2015, and it was 33% higher than the one in 2014, possibly due to an increased amount of rainfall in August (105.8 mm), in comparison to the long-term average (68.3 mm). In addition, the highest irrigation effect was obtained in the year 2015, where the average NNP increased by 27% in the abundant treatment (I3), in comparison to the control treatment (I1). The NNP is a trait largely determined by genotype, so it proved to be a very practical selection goal in the development of the new high-yielding genotypes (Kahlon et al., 2011). The NSP was under the strongest effect of the year, but irrigation also had a significant effect on the NSP. In general, the largest NSP was observed in 2015, and it was 20% and 31% higher if compared to 2013 and 2014, respectively. An abundant irrigation resulted in the highest NSP in comparison to the rational and control treatment. The largest difference is observed between the abundant and control treatment, where the abundant treatment resulted in an NSP higher by 24%, when compared to the control treatment (Table 2). Demirtaş et al. (2010) concluded that the NSP is a yield component most sensitive to the stress during the seed growth. The NSP has the highest correlation coefficient and a high and positive effect on the yield, so the selection of high-yielding genotypes based on this trait can be performed directly disregarding the alternating weather conditions (Varnica, 2018). Irrigation, year, and their interaction did not have a statistically significant effect on the TSW (g), but, according to the obtained data, the lowest average TSW (g) was attained in the control treatment (I1) in each examined year. Furthermore, in each year, the highest average TSW (g) was obtained in the abundant irrigation (I3). The largest difference between the I1 and I3 was observed in the year 2015, where the TSW (g) in the abundant treatment was 11.4% higher in comparison to the I1.

Table 2. Treatment effect on the soybean yield components

Tablica 2. Utjecaj tretmana na komponente prinosa soje

		SY (t ha^{-1})	TSW (g)	NNP	NSP
Irrigation (I) / *Navodnjavanje (I)*					
I1		3.337 ± 81.69[c]	169.6 ± 3.42	12.25 ± 0.26[b]	127.4 ± 3.42[b]
I2		3.882 ± 43.48[b]	177.5 ± 3.40	13.66 ± 0.42[a]	133.5 ± 5.74[b]
I3		4.092 ± 51.93[a]	179.0 ± 3.61	13.86 ± 0.37[a]	157.5 ± 5.56[a]
F		49.8	2.07	17.77	14.14
p		< 0.001	0.131	< 0.001	< 0.001
Year (Y) / *Godina (Y)*					
2013		3.883 ± 80.89[a]	172.6 ± 3.03	14.07 ± 0.18[b]	134.7 ± 5.17[b]
2014		3.803 ± 52.73[a]	176.2 ± 4.03	11.02 ± 0.20[c]	122.7 ± 3.36[c]
2015		3.625 ± 98.09[b]	177.2 ± 3.47	14.68 ± 0.36[a]	161.0 ± 5.49[a]
F		5.72	0.47	88.5	21.43
p		0.0045	0.628	< 0.001	< 0.001
Interaction (I x Y) / *Interakcija (I x Y)*					
2013	I1	3.387 ± 110.16[cd]	168.6 ± 5.81	13.44 ± 0.27[bc]	122.38 ± 5.18
	I2	4.034 ± 61.00[ab]	175.2 ± 5.33	14.46 ± 0.29[ab]	131.05 ± 9.38
	I3	4.228 ± 106.55[a]	174.1 ± 4.80	14.30 ± 0.31[abc]	150.66 ± 10.08
2014	I1	3.624 ± 112.27[bc]	172.9 ± 7.37	10.82 ± 0.27[d]	120.14 ± 5.53
	I2	3.840 ± 47.02[abc]	178.9 ± 7.06	10.83 ± 0.41[d]	112.10 ± 3.56
	I3	3.945 ± 82.90[ab]	176.8 ± 7.01	11.41 ± 0.37[d]	135.86 ± 6.15
2015	I1	2.999 ± 144.45[d]	167.1 ± 4.70	12.48 ± 0.40[cd]	139.55 ± 5.81
	I2	3.772 ± 93.55[abc]	178.4 ± 5.59	15.70 ± 0.51[a]	157.53 ± 10.91
	I3	4.104 ± 62.08[ab]	186.2 ± 6.72	15.85 ± 0.36[a]	186.05 ± 5.88
F		4.69	0.48	6.63	1.34
p		0.0017	0.751	< 0.001	0.260

SY – seed yield, NNP – number of nodes per plant, NSP – number of seeds per plant, TSW (g) – thousand seed weight. Mean values denoted by different letters are significantly different at a significance level of 99%, in conformity with the LSD test.

The seed yield data were used within the regression models for a seed yield prediction based on the TSW (g), NNP, and the NSP at different irrigation levels, presented in Figure 1. Irrigation had a significant effect on the seed yield, confirming the observations of numerous authors (Maleki et al., 2013; Torrion et al., 2014; Irmak and Sharma, 2015; Nunes et al., 2016). In general, regardless of the year effect, the lowest seed yield was obtained in the control treatment (I1) (Fig. 1). The largest irrigation effect on the seed yield was obtained in the year 2015, when the abundant treatment (I3) increased the seed yield by 36.8%, in comparison to the control treatment. In the years 2013 and 2014, in comparison to the control treatment, an increase in the seed yield of the abundant treatment was lower than in 2015 (24.8% and 8.8%, respectively), but it was also statistically significant. The obtained regression models for the seed yield prediction in the control treatment and rational irrigation were not statistically significant (Table 3).

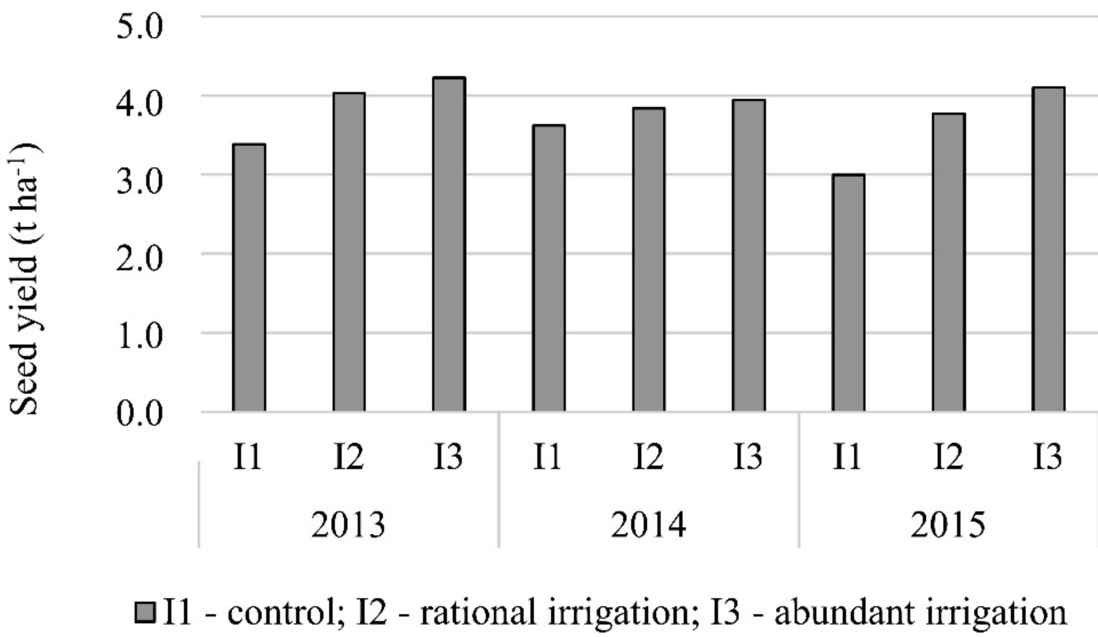

Figure 1. Seed yield at different irrigation levels
Grafikon 1. Prinos sjemena ovisno o navodnjavanju

Table 3. Unstandardized regression models B coefficients at different irrigation levels
Tablica 3. Nestandardizirani B koeficijenti regresijskih modela pod različitim uvjetima navodnjavanja

	Control (I1)		Rational (I2)		Abundant (I3)	
	Unstandardized B coefficient	p	Unstandardized B coefficient	p	Unstandardized B coefficient	p
y-intercept	2529.113	0.000	3416.632	0.000	3213.977	0.000
TSW (g)	2.209	0.365	1.910	0.205	0.983	0.492
NNP	36.782	0.140	3.470	0.782	5.157	0.727
NSP	-0.136	0.944	0.592	0.508	4.019	0.000
	R = 0.164		R = 0.139		R = 0.479	
	F = 0.959		F = 0.687		F = 10.32	
	p = 0.415		p = 0.562		p < 0.001	

On the other hand, in the abundant irrigation, a regression model based on the TSW (g), NNP, and the NSP in their capacity as the predictors produced a statistically significant model for the seed yield prediction, but only the NSP was determined as a significant predictor. There is a positive and significant correlation between the seed yield and the TSW (g) (Kumudini et al., 2001, Showkat and Tyagy, 2010). Moreover, only 47.9% of seed yield variability could be explained by a variability in the prediction variables, indicating that other factors play an important role in the production of soybean seed yield, besides the aforementioned prediction variables. Salimi and Moradi (2012) argue that recognizing a relationship between the yield and its components, available through the correlation and regression analyses, greatly assists the formulation of soybean selection. The highest correlation coefficient (0.545) was obtained between the number of nodes per plant and the number of grains per plant, followed by the grain yield and the number of grains per plant (0.466) and by the grain yield and the number of nodes per plant (0.295; see Table 4).

Table 4. Correlation coefficient between the seed yield (Y), number of nodes per plant (NNP), number of seeds per plant (NSP) and thousand seed weight (TSW) (g) in the abundant irrigation (I3)

Tablica 4. Korelacijski koeficijent između prinosa (Y), broja plodnih etaža (NNP), broja zrna po biljci (NSP) i mase 1000 zrna (TSW) (g) u obilnome navodnjavanju (I3)

	Y	NNP	NSP	TSW
Y	1			
NNP	0,295*	1		
NSP	0,466*	0,545**	1	
TSW	0,085	–0,014	–0,110	1

CONCLUSIONS

In this study, the experiment and statistical data analysis confirmed that water is a limiting factor in the achievement of stable soybean seed yields. The NSP was determined as one of the yield components that makes a significant contribution to the final seed yield. Based on the set regression models, the relationships between the soybean yield and its components generated equations to estimate the yield and assess prediction accuracy and its significance level. In the abundant irrigation (I3), a regression model based on the TSW (g), NNP, and NSP in their capacity as the predictors produced a statistically significant model for the prediction of seed yield, but only the NSP was determined as a highly significant yield predictor. Given the seed yield dataset used, it can be concluded that a strong linear relationship between the soybean yield and the NSP was present, as was the one between the NSP and the NNP in the abundant irrigated variant. A weak linear relationship between the NNP and the TSW (g) was also evident. The results indicate that the irrigation is a major factor that influences a variation in the soybean seed yield and its components over the years. Future research will be directed to determine the relationship and strength of the yield components and the seed yield, as well as their reactions to the agrotechnical operations.

ACKNOWLEDGEMENTS

This work was supported by the Faculty of Agrobiotechnical Sciences Osijek as a part of the scientific project entitled *AgroGIT—Technical and Technological Crop Production Systems, GIS, and Environment Protection*.

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ODNOS KOMPONENATA PRINOSA I PRINOSA ZRNA SOJE (*Glycine max* L. Merr.) U UVJETIMA NAVODNJAVANJA

SAŽETAK

Ovo istraživanje predstavlja rezultate trogodišnjih pokusa (2013 .– 2015.) s ciljem utvrđivanja odnosa između komponenata prinosa soje i prinosa zrna pri različitim tretmanima navodnjavanja. Rezultati su pokazali da je godina istraživanja imala najveći utjecaj na broj etaža po biljci (NNP), dok je interakcija navodnjavanja i godine pokusa također statistički značajna. Najviši prosječni NNP zabilježen je 2015. godine i bio je 33 % veći u odnosu na 2014. godinu. Najveći broj zrna po biljci (NSP) zabilježen je 2015. godine, a bio 20 % i 31 % veći u odnosu na 2013. i 2014. godinu. Bogato navodnjavanje rezultiralo je najvećim NSP-om u usporedbi s racionalnim i kontrolnim tretmanom. Navodnjavanje, godina istraživanja i njihova interakcija nisu imali statistički značajan učinak na masu tisuću zrna (TSW) (g), ali je najniži prosječni TSW (g) postignut u kontrolnome tretmanu svake godine ispitivanja. Regresijski modeli za predviđanje prinosa zrna u kontrolnome tretmanu i racionalnome navodnjavanju nisu bili statistički značajni. Međutim, u bogatome navodnjavanju, regresijski model temeljen na TSW-u (g), NNP-u i NSP-u kao prediktorima dao je statistički značajan model za predviđanje prinosa zrna, ali samo je NSP identificiran kao visoko značajan prediktor prinosa zrna.

Ključne riječi: soja, navodnjavanje, komponente prinosa, korelacija, procjena prinosa

(Received on November 4, 2021; accepted on January 25, 2022 – *Primljeno 4. studenoga 2021.; prihvaćeno 25. siječnja 2022.)*