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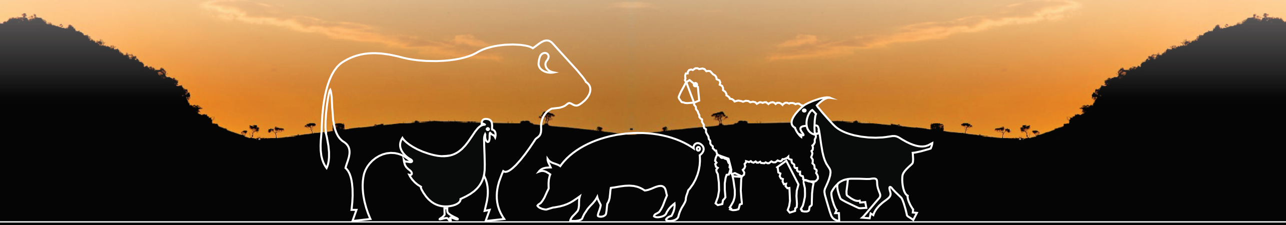

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EFFECT OF WATER STRESS ON SOYBEAN PRODUCTION

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Invited paper

Abstract:

Soybean is main source of vegetable protein and oil in the world. Soybean used for livestock feed, human food and industrial processing. Soybean is main raw material for the preparation of a protein feed for all types and categories domestic animals. In the world the largest part of soybean produced, about 70% is used to feed livestock. In Serbia the area under soybeans and grain yield varies from 144386 ha to 170255 ha and 1.73 t ha^{-1} and 3.18 t ha^{-1}, respectively. Grain yield depends on the amount of rainfall from late June to early September when the highest needs for water (since beginning of flowering until the end of grain filling). Soybean is most sensitive to drought stress during the pod formation and grain filling stages.

Key words: drought, soybean, area, production, yield

Introduction

The economic and agro-technical importance of soybean (*Glycine max* (L.) Merr.) is very large in Serbia and the world. It is a multipurpose crop, ideal for livestock feed, for human food, and industrial processing. Soy protein is the best plant proteins. The great economic importance of soybean reflected in the high nutritional value of grain. Commercial varieties of soybean in grains contain an average 40% protein, 20% oil, 35% carbohydrate, and 5% ash on a dry-weight basis *(Liu, 1997)*. In world, livestock industry is the largest consumer of soybean meal as a byproduct in processing. Thus, in the U.S.A. 98% soybean meal goes to feed cows, pigs and chickens *(Soyatech, 2014)*. Soybeans can be used as soybean meal, cake and a green mass, hay and silage for livestock feeding. For the production of green mass, soybean can be grown as a pure crop or in mixtures with other plants (maize, sorghum, sunflower). When grown as pure crop, it can give

30-50 t ha^{-1} of green mass, which provides 1000 to 1500 kg of high-quality protein and 800 to 1000 kg of mineral substances. Soybean produces a high yield of green mass in intercropping (25-40 t ha^{-1}). However soybean grain contains a complex of antinutritive substances (trypsin inhibitors, hemagglutinin, saponin, goitrogens factors, allergens, flatulene substances lipoksidaza, urease) which is why it must be heat-treated before use. Therefore, the selection of soybean varieties is focused on creation of Kunitz trypsin inhibitor (KTI) free varieties in the mature grain (*Srebrić, 2013*). KTI free varieties in the mature grain can be used in the diet of adult non-ruminant animals without heat treatment thereby reducing costs of production of animal feed (*Ranđelović et al., 2004; Ranđelović et al., 2006)*. In the industrial processing, grain of these varieties is processed at a lower temperature and for a shorter time, reducing processing costs, while beneficial proteins are denatured to a lesser degree (*Ranđelović, 2009*). In the soybean production in Serbia two Kunitz trypsin inhibitor free varieties of soybean are implemented - Laura (I maturity group) and Lana (maturity group II) that do not require specific growing conditions in relation to the varieties of standard grain quality. Results by *Ranđelović et al. (2006), Ranđelović (2009)* and *Ranđelović et al. (2010)* showed that cultivar Lana had higher grain yield then cultivar Laura. *Ranđelović et al. (2009)* concluded that the cultivar Lana was more productive in climatically favorable year, while variety is Laura, with shorter vegetation period, in arid year. In order for raw soybean to be used in the diet of young domestic non-ruminant animals, it has to be free of KTI and lectins *(Palacios 2004)*. In Serbia, soybean it is a major ingredient in livestock feed, very little used in the human food and industrial processing *(Ranđelović, 2009)*. Soybean seeds used as a supplement to cereal seeds in feed dairy cows, cattle, pigs, goats, sheep, horses and poultry *(Iqbal et al., 2003; Ranđelović, 2009)*. The soybean meal and soybean flour used in the nutrition of livestock, poultry and fish *(Popović et al., 2009, 2011, 2013)*. *Todorović and Kondić (1993)* concluded that the one kilogram of soybean flour is equivalent to 2.3 kg of meat and 12 litres of milk. The soybean flour is used in the baking industry. Soybeans represent 50 percent of world oilseed production. The soybean oil used in food industry, while lecithin (component of soybean oil) apart from being used in food industry for production bakery and confectionery products, has its application in medicine, textile and chemical industries. Soybean oil is used for biodiesel production.

The agro-technical importance of soybean reflected in crop rotation, because enriches the land with nitrogen. Nitrate-fixing symbiotic bacteria *Bradyrhizobium japonicum* on soybean root convert inorganic nitrogen N_2 from the atmosphere into a form NH_2 (form appropriate for the plant). *Bethlenfalvay et al. (1990)* reported that the soybean-*Bradyrhizobium* symbiosis can fix from 40 to 300 kg N ha^{-1} per year, which is equivalent to 500-1000 kg ha^{-1} of mineral nitrogen fertilizers. Also, soybean it improves the physical and chemical properties of the soil. Soybean his powerful developed and deep root system has a positive influence on physical (structure) and chemical properties (fertility) of the soil. Root secretions have a positive influence on maintaining and improving fertility in soil because activated the nutrient mobility and nutrient mineralization (i. e., the breakdown of nutrients into plant usable forms) *(Hrustić et al., 1998).*

World, USA and Serbia soybean production

The total harvested area under soybean in the world for the 2009-2013 periods was 104.5 million ha, total production 253.5 million tons and average grain yield 2.43 t ha^{-1} *(FAOSTAT, 2014),* Table 1.

Table 1. Harvested area, production and grain yield in soybean in world, USA and Serbia, 2009-2013 *(FAOSTAT, 2014)*

Year	Harvested area, ha			Production, t			Grain yield, t ha^{-1}		
	World	USA	Serbia	World	USA	Serbia	World	USA	Serbia
2009	99337807.58	30906980	144386	223411328.80	91417300	349193	2.25	2.96	2.42
2010	102807828.03	31003300	170255	265120391.98	90605460	540859	2.58	2.92	3.18
2011	103816640.88	29856410	165253	261886302.22	84191930	440847	2.52	2.82	2.67
2012	105018859.07	30798530	162714	240971129.75	82054800	280638	2.30	2.66	1.73
2013	111544703.08	30703000	159724	276032361.62	89483000	385214	2.48	2.91	2.41
M	104505167.73	30653644	160466	253484303.87	87550498	399350	2.43	2.85	2.48
Index, %	100.00	29.33	0.15	100.00	34.54	0.16	100.00	117.28	101.02

Soybean is grown mainly from 0° to 55° latitude and below to 2000 m elevation, but most commercial production is between 25° to 45° latitude and below 1000 m elevation *(Fageria et al., 2010).* The USA, Brazil, Argentina, China and India are the largest producers of soybeans, yielding more 92% of the total world production. The European largest soybean producers are the Russian Federation, Ukraine, Italy, Republic of Serbia and Romania *(Vlahović et al., 2013).*

Harvested area, total production and grain yield of soybean in the Republic of Serbia for the 2009-2013 periods was the 160466 ha, 399350 tons and 2.48 t ha^{-1}, respectively. Harvested area, total production and grain yield of soybean in Serbia vary among years in range from 144386 ha (2009) to 170255 ha (2010), 280638 t (2012) to 540859 t (2010) and 1.73 t ha^{-1} (2012) to 3.18 t ha^{-1} (2010), respectively. Unstable and reduced soybean yields in Serbia are the result of insufficient amount and irregular distribution of rainfall during the growing season, especially from late June to early September (from the beginning of flowering until the end of grain filling). *Mandić et al. (2013)* reported that in Serbia the variation of rainfall regime is typical during summer seasons. *Srebrić and Perić (2014)* state that the extremely dry summer of 2012 led to a significant reduction grain yield, while *Đukić et al. (2014*) reported that 2010 was the favorable year for soybean production. The five-year average grain yield of soybean in Serbia is higher for 1.02% (0.05 t ha^{-1}) than average grain yield of soybean in world, but lower for 87.02% (0.37 t ha^{-1}) than average grain yield of soybean in USA. Introduction of irrigation would enable the achievement of high and stable yields of soybean and the changing climatic conditions in Serbia. However, in Serbia are irrigated about 1% of arable land *(Mandić et al., 2013)*.

Effect of water stress on soybean production

The soybean water requirement in Serbia is 450-480 mm during the growing season *(Glamočlija, 2012)*. Monthly needs of soybeans for water are the following: 10 to 40 mm in April, 30 to 60 in May mm, 90-110 mm in June, 100 to 125 mm in July, 100 to 120 mm in August, 50 to 80 mm in September and 40 mm in October. The highest needs for water are since beginning of flowering until the end of grain filling, when soybean crop consumes 60-90% of total water needed. This, depending on the maturity group, refers to the period from late June to early September *(Srebrić and Perić, 2014)*. *Dolijanović et al. (2013)* reported that 1 mm of annual rainfall increase the soybean grain yield from 2.1 to 2.9 kg ha^{-1}. Drought and high temperatures during flowering and grain filling stages causes abortion of flowers, reduced pod number, number of seeds per pod, and grain remains small *(Ranđelović, 2009).* Commercial varieties developed in Serbia have stem of indeterminate growing type which means that on the same plant basically formed pods appear, in the central part the open flowers and on the top of the stem new leaves are still emerging. During growth, stem flowering takes place successively from the lower nodes to the top and lasts 3-4 weeks. Long flowering compensates rejection/abortion of flowers and pods that occurs in case of drought. The plant rejects flowers or pods already formed in the lower part, while the top of the stem emphasizes the formation of new flowers. The level of compensation is gradually reduced with the end of flowering, and completely ceases with the completion of the formation of flowers, which is in the mid-stage of grain formation. This is why the worst effects of drought are in the mid-stage of the formation of the pods to the mid-stage of grain formation. In addition, soy begets more flowers per plant than it has the potential to feed the pods, usually only 25-30% of flower conceived are formed. Soybean yield may be reduced if during the grain filling stage, which lasts until the mid-stage of full grain formation, a drought occurs. The negative consequences of long flowering is uneven ripening which on one hand makes it difficult to harvest, and on the other hand increases the risk of seed loss, as the ripe pods shatter easily at harvest. During flowering and pod set temperatures above

32°C leads to abortion of flowers and decline of pods (*Glamočlija, 2012*). High temperatures and drought in the summer months lead to faster maturing of soybean crops with shortening of flowering and grain filling stages. Unfavorable climatic conditions reduce soybean grain yield by 24% to 54% (*Kobraee and Shamsi, 2012*). *Bošnjak (2004)* states that the grain yield of soybean is highly significantly correlated with the amount of rainfall in the growing season and with the amount of rainfall in June, July and August, when the soybean is flowering, pod formation and grain filling stages. Soybean yield significantly depends on the amount of rainfall in July and early August *(Vidić et al., 2009, Popović et al, 2015)*. Grain yield and yield components of soybean declined in drought stress *(Ranđelović et al., 2010; Kobraei et al., 2011; Mandić et al., 2015)*. *Mandić et al. (2015)* reported that quantitative traits of soybean (plant height, first pod height, number of nodes per plant, number of pods per plant, number of grain per plant, grain yield per plant, 1000-grain weight and grain yield) have the higher values in year with favorable distribution of rainfall. These authors reported that the drought stress in August (stage of grain filling) leads to a decrease in soybean grain yield (Figure 1). Also, *Ranđelović (2009)* and *Ranđelović et al. (2010)* concluded that the amount of rainfall in August has a decisive influence on soybean yield.

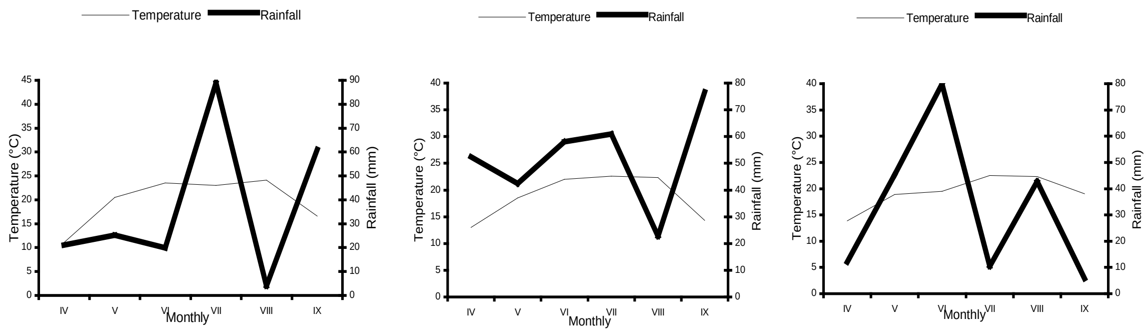

Figure 1. Climate diagram according to Walter in the 2003 for Ivanovo *(Ranđelović, 2009)*, 2008 for Putinci *(Mandić et al., 2015)* and 2009 for Putinci *(Ranđelović et al., 2010)*.

Drought stress during flower induction or flowering has lower influence on yield reductions than drought stress during either pod formation or podfill *(Doss et al., 1974, Ranđelović, 2009)*. *De Souza et al. (1997)* concluded that long water stress from the beginning of growth stage R6 (early in seed filling) until maturity, shortened the seed-filling period (R7 occurred up to 7 days earlier) resulting in smaller seeds (32%) and lower yield (44%). Also, short periods of water stress during seed filling might decrease yield by up to 23% *(Brevedan and Egli 2003)*. Water stress during vegetative and reproductive stages of soybean growth did not significantly affect the oil or protein content of seed and the fatty acid composition of the oil *(Dornbos and Mullen 1992)*. *Karam et al. (2005)* have found that the most critical stage for water stress is the R5 - R6 stages. *Dragović et al. (1993)* concluded that soybean is more sensitive to drought in R5-R8 reproductive stages than R1-R4 stages. Defensive mechanism of soybean against drought is also the fact that the root of soybean under drought conditions grows deeper into the soil and increases its density (*Purushothaman et al., 2013*). This increases water uptake and plant maintains a high potential for water and delays the dehydration.

Introduction of irrigation would enable the achievement of high and stable yields of soybean and the changing climatic conditions in Serbia. However, in Serbia is irrigated 1% of arable land *(Mandić et al., 2013)*. Therefore sowing soybean genotypes of certain maturity group should be adapted to agro-meteorological conditions of the site in order for them to express their maximum yield potential (*Ranđelović, 2009*). Soybean varieties of shorter growing period (0, I maturity group) are more suitable for planting in arid regions. Varieties of longer vegetation period (maturity group II) are recommended for growing in regions with favorable agro-meteorological conditions.

Conclusions

Harvested area, total production and grain yield of soybean in the Republic of Serbia for the 2009-2013 periods was the 160466 ha, 399350 tons and 2.48 t ha^{-1}, respectively. Harvested area, total production and grain yield of soybean in Serbia vary among years in range from 144386 ha (2009) to 170255 ha (2010), 280638 t (2012) to 540859 t (2010) and 1.73 t ha^{-1} (2012) to 3.18 t ha^{-1} (2010), respectively.

Production of soybean in Serbia is limited by drought in the summer months (from late June to early September) when are plants at flowering, pod-setting and grain-filling stages. Soybean is more sensitive to drought in R5-R8 reproductive stages (R5-R6 - seed development and R7-R8 - beginning and full maturity) than R1-R4 stages (R1-R2 - beginning and full bloom - and R3-R4 - beginning and full pod). Soybeans can tolerate short periods of heat and drought at early reproductive stages by aborting flowers and forming later. But the crop will not bloom indefinitely and under prolonged heat and drought.

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Uticaj vodnog stresa na produkciju soje

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Rezime

Soja je glavni izvor biljnih proteina i ulja u svetu. Soja se koristi u ishrani domaćih životinja i ljudi i u industrijsoj preradi. Soja je osnovna sirovina za izradu proteinske hrane za sve vrste i kategorije domaćih životinja. U svetu najveći deo proizvedene soje, oko 70%, koristi se za ishranu domaćih životinja.

U Srbiji površina pod sojom varira od 144386 do 170255 ha, a prinos zrna od 1,73 t ha^{-1} do 3,18 t ha^{-1}. Prinos zrna zavisi od količine padavina od kraja juna do početka septembra, kada su najveće potrebe za vodom (od početka cvetanja do kraja nalivanja zrna). Soja je najosetljivija na sušu tokom formiranja mahuna i nalivanja zrna.

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