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Simulation of the hail damage on regeneration and yield of soybean (*Glycine max* (L.) Merr.)

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Summary: The most common mechanical damage to soybean in the agroecological conditions of Serbia occurs after the appearance of hail, floods or due to damage from wild animals and insects. In recent years, extreme temperatures accompanied by drought have been increasingly recorded during the summer months, as well as the appearance of hail, which has become frequent during the growing season of spring crops. The aim of this work was to determine the consequences and the extent of yield reduction if hail occurs in the generative stages of soybean development. The occurrence of hail in the R1 (beginning bloom) and R3 (beginning pod) stages of development in the form of plant damage was simulated. This paper will present the results of how three soybean varieties reacted after simulated hail damage in two stages of generative development and what the effects were on yield, height, number of fertile nodes, as well as percentage of plant regeneration. The trial was set up in 2020 as a two-factorial experiment in three replications. Three soybean varieties were sown in late April. In order to simulate hail damage, the plants were cut to a height of 15 cm to ensure at least two nodes and enable the regeneration of the plants. The stage of development of soybean, i.e. the moment of hail damage, had a direct impact on the yield, the number of regenerated plants, as well as the number of fertile nodes.
Keywords: damage, hail, regeneration, soybean, yield

Introduction

In the Republic of Serbia, soybean crop is in third place in terms of production areas, being one of the three largest producers of soybean in Europe. At the same time, Serbia is the only country that is self-sufficient in the production and processing of this protein-oil plant species, which ensures the needs of the domestic industry for plant proteins (Živkov et al., 2016). Soybean is an important source of protein and oil, and the intensification of multidisciplinary research with the aim of increasing yields in different production conditions is extremely significant (Pagano & Miransari, 2016). Climate

changes also significantly impact crop production (Zarkovic et al., 2014), and adjustments of cultivation practices will be required.

During the past decade, more and more frequent occurrences of extreme weather conditions have cause great damage and losses to the agricultural sector (Bal et al., 2014). Unpredictable weather conditions in the region, particularly precipitation amounts and distribution, create fluctuations in agricultural yields (Vojnov et al., 2020; Babec et al., 2020). Although drought has been the most common occurrence in recent years, in the light of climate change, the appearance of hail has become more frequent (Nađ et al., 2021). Each year, hail causes significant losses in agriculture production in several European countries, including Serbia (Ćurić, 2012). The appearance of hail in recent years is considered frequent during the growing season of spring crops. The total number of days with hail in Serbia can vary by more than two times (Ćurić et al., 2015), whereby, depending on the stage of crop development, significant damages can occur that directly affect the success of agricultural production. In Vojvodina Province, hail can most often occur in May, June and July, which coincides with the soybean growing season. Soybean is a plant species that has an exceptional power of regeneration in case of hail damage, especially if damage occurs during the vegetative growth period (stages V1-V6). The percentage of regenerated plants depends on the degree of damage and at what stage of growth and development the damage occurred. After damage, plant regeneration begins, in the form of the formation of lateral branches, usually on the lowest undamaged node. Regeneration occurs if the main stem or one or two fertile nodes are not destroyed and then one or more side branches can develop, which later can easily take over the role of the main stem, so it is important to carefully inspect the soybean crop after the hail (Hicks et al., 2013). When hail occurs at a later stage of soybean crop development, it has a more negative impact (Zaitsev et al., 2021). When the plants are in the reproductive phase of growth (flowers or already formed pods) and if hail occurs, the damage is greatest since it directly affects the yield components. If damage from hail occurs in the late vegetative stages or during the reproductive stage, diseases may occur since the plant tissue injuries enable pathogens passage and greater or complete yield losses can be expected (Đorđević et al., 2015). The amount of hail damage is influenced by the following factors: type of crop, stage of crop development, intensity of hail (density); hail duration; weather conditions before and after hail; crop condition before hail; damage from disease, and mechanical damage to leaf mass from wind after hail. When it comes to hail, its size (diameter) is one of the critical factors in the damage it will cause to the crop (Bal et al., 2014). The most significant consequence of hail damage is the reduced number of plants per unit area, which is directly correlated with yield. The aim of this work was to analyse the consequences through yield reduction if hail occurs in the generative stages of soybean development, that is, to determine how three soybean varieties regenerated after simulated damage in R1 and R3 growth phases.

Material and method

The trial was set up at the Rimski Šančevi experimental site of the Institute of Field and Vegetable Crops, Novi Sad, Serbia in 2020. A field trial was designed as a two-factorial experiment in three replications. The first factor was the moment of damage, and the second factor was soybean variety. Three soybean varieties were sown in a strip (45 m long, 3 m wide), the plot size was 15 m × 3 m per replication, or 135 m^2 in total per soybean variety. Soybean varieties NS Atlas - 0 maturity group (MG), NS Apolo – I MG, and Rubin - II MG were selected for the trial. Crops were sown in late April (22 April 2020). In order to simulate hail damage, the plants were cut to a height of 15 cm, to ensure at least two nodes and enable the regeneration of the plants (the regeneration point was not destroyed). Damage (cuts) was simulated in soybean development stages R1 and R3, and undamaged plants were used for control (C). The simulation of hail was performed on 1 m^2 and the area around 1 m^2 was cut to avoid shading effect. At full maturity phase (R8), the number of plants was counted as

an indicator of loss of canopy. The following traits were measured: the number of fertile nodes, and plant height (cm) and grain yield (t/ha) were measured. On the area of 1 m^2 per treatment before cut the number of plants were calculated. Samples for grain yield were taken manually on 1m2 and calculated for 1 ha. Per each treatment the height and nodes number were measured on 5 plants per each replication (average value was used for statistical analysis). The node number was calculated on lateral branches, since central stem was irreversibly damaged. The same plants were used for measurement of plant height and node number and for grain yield. All regular cultivation practices from sowing to harvesting were applied in the experiment. After harvesting, the yield, the height of the plants was measured, and the percentage (%) of regenerated plants was calculated. The data were processed by two-factorial ANOVA, and the significance of the differences between the investigated treatments was tested using the LSD test. A statistical program (STATISTICA 13.5) was used for the statistical processing of the above results, and the Microsoft Office Excel program was used to prepare the figures.

Results and Discussions

The results of the analysis (F test) showed that the moment or stage of soybean development when plant damage occurred has a highly significant influence on the percentage of plant regeneration. The regeneration value (%) of treatment c (without simulated damage in earlier stages) was 100%. Treatment c, i.e. control, was assigned a regeneration value of 100%, on the basis of which the comparison and calculation of the assessment was made. Comparing these average values of the number of regenerated plants if damage occurs in the R1 and R3 phases (Fig. 1), the regeneration of plants if damage occurs is better in earlier stages of development. If the damage occurs in the R3 phase, the plants wilt and the number of surviving/regenerated plants is small, which directly affects the canopy and therefore the yield. Regardless of the nodes being left, when there is damage in the reproductive stages, the plants irreversibly wither. This is in accordance with Đorđević et al. (2015) when the plants are in the reproductive phase of growth (flowers or already formed pods), and hail occurs, the greatest damage can occur, and the yield reduction is more pronounced.

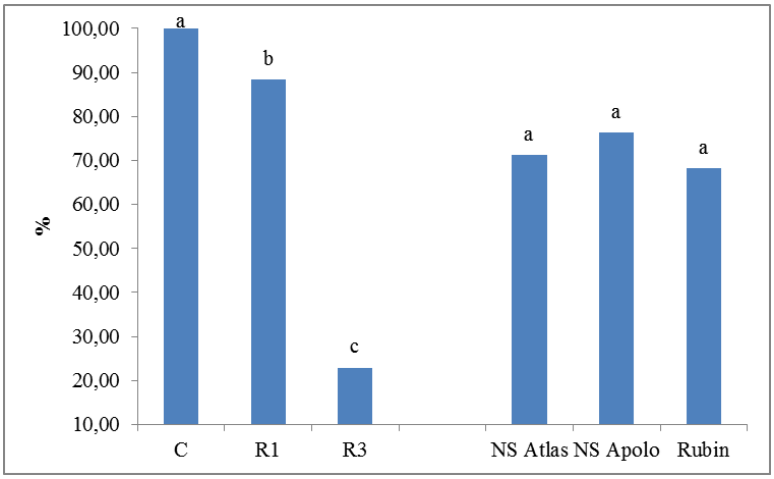

Figure 1. Percentage of regeneration of soybean plants in the R8 phase (after damage in the R1 and R3 phases, and C is the control without damage). Letters represent statistically significant differences between average values achieved on treatments within one factor.

The results of ANOVA showed that the moment of plant damage had a significant effect on soybean plant height. In relation to the moment when the damage occurred, the height of the plants

was different, where the highest average plant height was observed in the varieties NS Atlas and Rubin, which are the tallest and it formed the largest number of lateral branches, which is its genotypic characteristic (Fig 2.).

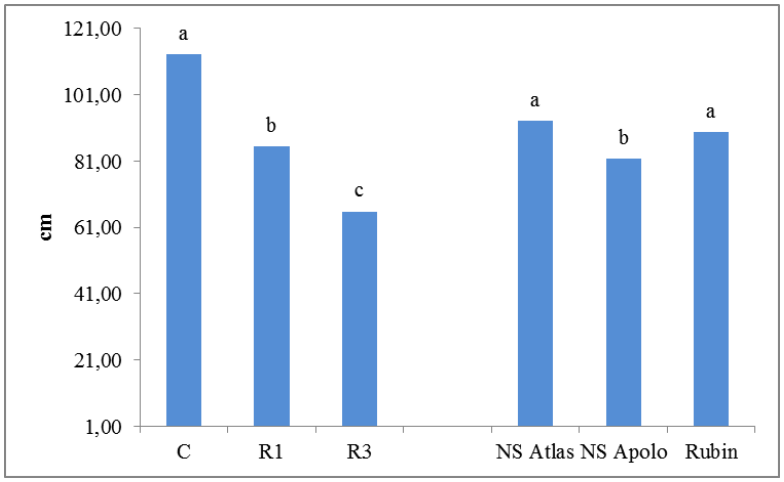

Figure 2. Plant height (cm) in the R8 phase after plant regeneration. Letters represent statistically significant differences between average values achieved on treatments within one factor.

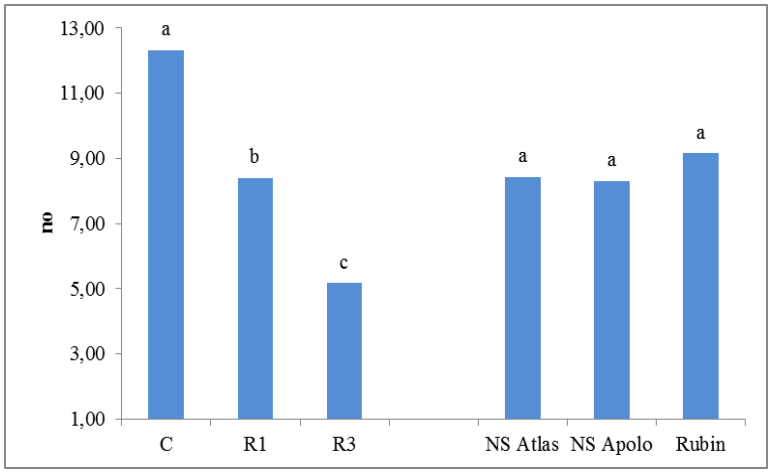

Figure 3. Number of fertile nodes in the R8 phase after regeneration. Letters represent statistically significant differences between average values achieved on treatments within one factor.

The moment when the damage occurred stood out as a significant factor in the number of developed fertile nodes. In the case of the number of fertile nodes, in relation to the phase when the damage occurred, a significantly lower number of fertile nodes was formed, in the R1 phase (8) compared to soybean that regularly completed the vegetation (12) (Fig. 3). When the damage occurred in the stage R3, the ability of the plants to regenerate was much lower (5 nodes).

The majority of soybean cultivation in Vojvodina occurs through rainfed methods (Pejić et al, 2012). During the vegetation season, the required amounts of rain in the agroecological conditions of Vojvodina range from 450 to 480 mm, and soybean water requirements vary during the growing season depending on the stage of development and the average daily temperatures during the growing season (Miladinović, 2012). The year 2020 was favourable for soybean cultivation, due to the favourable

rainfall distribution. The amount of precipitation in the period from April to September was 466.5 mm, while the average air temperature in the same period was 19.03°C. During 2020, the occurrence of hail was not recorded. In relation to the stage of development in which the damage occurs, the influence of the moment of hail damage on soybean yield is clearly visible (Fig. 4).

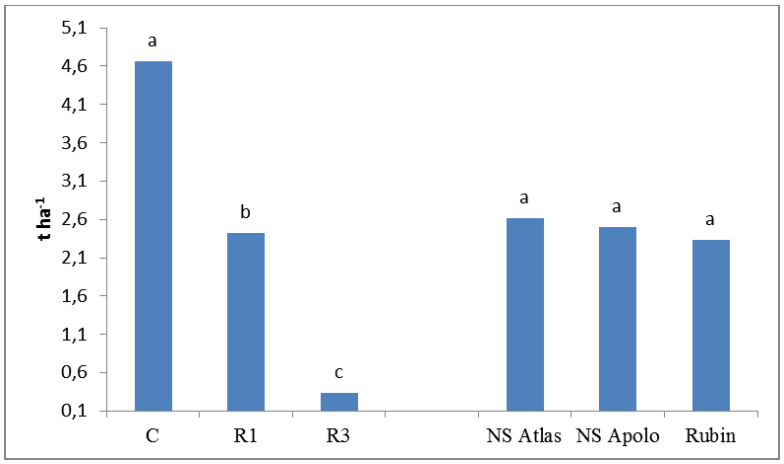

Figure 4. Soybean grain yield in the R8 phase. Letters represent statistically significant differences between average values achieved on treatments within one factor.

The highest grain yield was achieved on the control plot, which had an average yield up to 5 t ha^{-1} where there was no damage in the earlier stages of growth, while a significantly lower grain yield was achieved on the treatments where hail damage was simulated in phase R1 (2.54 t ha^{-1}), as well as in phase R3 (0.34 t ha^{-1}). Fig. 4 shows the yield after damage in certain reproductive stages of soybean development (R1 and R3) compared to the control (C). The moment of plant damage had a significant impact on the yield of soybean and compared to the control (C), the greatest reduction in yield was recorded in soybean when the damage occurred in the R3 phase.

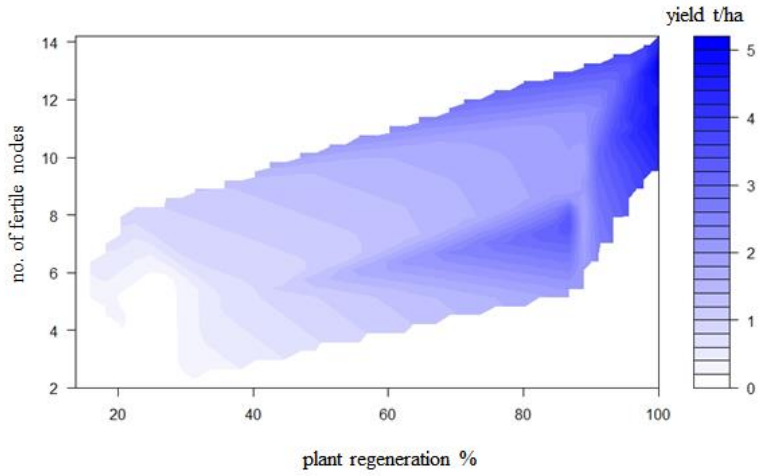

Figure 5. Summary overview of correlation of soybean regeneration, grain yield and number of fertile nodes

The number of regenerated plants, the number of fertile nodes, and the soybean yield are all affected directly by the stage of development, or the moment of when hail damage occurred. The Figure 5 clearly presents the relation among number of fertile nodes and yield as well as percentage of regeneration and gained yield.

Conclusions

Hail can cause significant damage in agricultural production, and information on the potential regeneration of selected soybean genotypes, as well as making a replanting decision, are of great practical importance. The stage of development of soybean, i.e. the moment of hail damage, has a direct impact on the yield, the number of regenerated plants, as well as the number of fertile nodes. There were no statistically significant differences between selected varieties on the number of nodes and yield. Whether soybean regenerates, depends on a large number of factors, but the most important of them is at what stage of development the damage occurred and to what extent. If hail occurs at the beginning of the soybean growing season, producers have several options, to replant the plot, or to wait, since in most cases the regeneration of soybean plants occurs, or to decide to plant some other plant species that could fit into the existing crop rotation.

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Simulacija oštećenja od grada na regeneraciju i prinos soje (*Glycine max* (L.) Merr.)

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Sažetak: Najčešća mehanička oštećenja na biljkama soje u agroekološkim uslovima Srbije nastaju nakon pojave grada, poplava ili zbog oštećenja od divljači i insekata. Poslednjih godina sve više su zabeležene ekstremne temperature praćene sušom u toku letnjih meseci, kao i pojava grada koja je postala česta u toku vegetacionog perioda jarih kultura. Cilj ovoga rada je da se utvrdi kakve su posledice i kolika mogu biti smanjenja prinosa ukoliko dođe do pojave grada u generativnim fazama razvoja soje, te je simulirana pojava grada u R1 (početak cvetanja) i R3 (početak stvaranja mahuna) fazi razvoja u vidu oštećenja biljaka. U ovom radu će biti prikazani rezultati kako su reagovale tri sorte soje nakon simuliranog oštećenja od grada u dve faze generativnog razvoja i kakav je uticaj na prinos, visinu, broj fertilnih nodija, kao i na procenat regeneracije biljaka. Ogled je postavljen 2020. godine kao dvofaktorijalni eksperiment u tri ponavljanja. Tri sorte soje su posejane u poslednjoj dekadi aprila. Za simulaciju oštećenja od grada, biljke su posečene na visinu od 15 cm, kako bi se obezbedila najmanje dva nodusa i omogućila regeneracija biljaka. Faza razvoja soje, odnosno momenat oštećenja od grada, ima direktan uticaj na prinos, broj regenerisanih biljaka, kao i broj fertilnih nodusa.

Ključne reči: grad, oštećenje, prinos, regeneracija, soja