

## Response of soybean and barley to Fertdolomite application on acid soil

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**Abstract:** The stationary field experiment with the application of granulated dolomite ( $\text{MgCO}_3 \times \text{CaCO}_3$ ) enriched with nitrogen, phosphorus and potassium (Fertdolomite: 24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 %  $\text{P}_2\text{O}_5$  + 3.0 %  $\text{K}_2\text{O}$ ) in rates 0, 5, 10, 20, 30 and 40 t ha<sup>-1</sup> on standard fertilization was started on 13<sup>th</sup> November 2007 on the acid soil (pH in 1n KCl: 3.90). The trial was conducted by randomized block design in four replicates (basic plot 40 m<sup>2</sup>). Standard fertilization of trial was applied in the next years for crops in rotation. In this study the response of soybean (2010) and winter barley (2012/2013) was shown. The average grain yield of soybean was 4830 kg ha<sup>-1</sup> with variation among the treatments ranging from 4341 to 5361 kg ha<sup>-1</sup>. At the rates 10 t ha<sup>-1</sup> and 20 t ha<sup>-1</sup> soybean yields were significant increased for 8% and 16%, respectively and additionally by 6% at the highest rate of fertolomite. Fertdolomite had a moderate positive effect on protein contents in grain, while oil content was independent on the treatments. The average grain yield of barley was quite low (3630 kg ha<sup>-1</sup>), mainly due to low ears density (average 493 per m<sup>2</sup>) which was affected by oversupplies of precipitation in winter period under less permeable soil conditions. Extreme variations of precipitation regime are in connection with climatic change. Due to the application of 10 and 20 t ha<sup>-1</sup> of Fertdolomite, yields of barley were significantly increased by 20% and 34%, respectively. However, the rates of 40 t ha<sup>-1</sup> showed a non-significant difference of the barley yield as compared to the control level. The ear densities were significantly increased by application  $\geq 10$  t ha<sup>-1</sup> Fertdolomite rates. Improvement of soil status by liming, adequate fertilization and similar managements contribute to the alleviation of detrimental effects of soil limitations and recent climate change on field crop yields.

**Keywords:** soybean, barley, Fertdolomite, grain yield, climate change

### Introduction

Soil acidity considerably limits crop yields worldwide. The aluminium (Al) toxicity and phosphorus (P) deficiency are considered to be two main constraints for crop production in acid soils (von Uexkull and Mutert, 1995, Sumner and Noble, 2003; Sarkar and Sharma, 2005). Acid soil in Croatia account for 1.6 mill. ha (Bogunovic et al., 1997), while Mesic et al. (2009) noted that in Croatia, 831704 ha or 32% of agricultural soil is acid. Also, with more than 50% of acid soils in all agricultural land in Croatia, soil acidity is recognized as a big problem (Bogunovic et al., 2016). Excessive soil acidity can be alleviated or neutralized by the addition of different lime materials containing calcium (Ca) and magnesium (Mg) ions. The correction of acid soil pH close to neutrality and improvement of nutrient availability by adequate fertilization, could be contribute to more favorable environment conditions for crop growth and for this reason to alleviate negative effects of soil properties (Stojic et al., 2012;

Jolankai and Birkas, 2013). Antunovic et al., (2014) and Tang et al. (2003) also showed that lime applied on the soil surface has brought about a short-term and long-term decrease in soil acidity. Low soil pH often associated with P deficit cause the soil infertility problem and for a sustainable soybean and barley production both lime and P fertilization is recommended. Temesgen et al. (2017) reported a yield increase in barley by 58% due to liming and by 44% due to P fertilization. Lokia et al. (2017) found in the pot experiment in acid soil that liming resulted in an increase total biomass of maize by 45%, root volume by 50% and plant height by 36% in comparison to the control.

Recent climate change characterized by global warming and frequently extreme variation of the precipitation regime has additional detrimental effect on productivity of acid and other soil types that are reflected in decreased yields of the main field crops (Rosenzweig et al., 2002; Cindric et al., 2009; Parry et al., 2005; Lobell and Field 2007; Lobell et al., 2007; Magas, 2013; Osborne et al., 2013; Lesk et al., 2016; Bootsma et al.,

2015; Zipper et al., 2016). According to UN data (2017) the average global temperature increased by 0.85 °C from 1880 to 2012. To put this into perspective, for each degree of temperature increase grain yields decline about 5%. Maize, wheat and other crops have experienced significant yield reductions at global level of 40 megatons per year between 1981 and 2001 due to warmer climate. Schenkler and Roberts (2008) estimated that in the United States yield increase under the temperature of up to 29 °C for maize and 30 °C for soybeans, but temperatures above these thresholds become very harmful. Appropriate soil management including liming of acid soil combined by adequate fertilization could contribute to the alleviation of negative effects of climate change on crop production.

The aim of this study was to test subsequent effects of granulated dolomite enriched with nitrogen, phosphorus and potassium (trade name Ferdolomite) applied in autumn of 2007 on soybean in 2010 and winter barley in 2013 growing seasons under acid soil conditions in central Croatia. Both growing seasons were characterized by unfavorable monthly distribution and considerable excess of precipitation in comparison to the long-term averages in the period 1961-1990.

## Material and methods

### *The field experiment*

The stationary field experiment with the application of granulated dolomite enriched with nitrogen, phosphorus and potassium (trade name Ferdolomite: 24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 % P<sub>2</sub>O<sub>5</sub> + 3.0 % K<sub>2</sub>O) started on 13<sup>th</sup> November 2007 on the Kolar Family Farm in Pavlovac (municipality Veliki Grdjevac, Bjelovar-Bilogora County). Ferdolomite was applied on the standard fertilization in the amounts of 0 (the control), 5 t ha<sup>-1</sup>, 10 t ha<sup>-1</sup>, 20 t ha<sup>-1</sup>, 30 t ha<sup>-1</sup> and 40 t ha<sup>-1</sup>.

The experiment was conducted by randomized block design in four replicates (basic plot 40 m<sup>2</sup>). After the distribution of NPK 7:20:30 fertilizer (500 kg ha<sup>-1</sup>) and Ferdolomite the soil was

ploughed to 25 cm depth. In the next years (from 2009 to 2015) only standard fertilization of the experiment was applied and subsequent effects of Ferdolomite were tested. The crop rotation on the experiment was as follows: maize (2008 and 2009) - soybean (2010) – winter wheat (2010/2011) – maize (2012) — winter barley (2012/2013) –maize (2014) – winter wheat (2014/2015). Standard fertilization of the experiment (kg ha<sup>-1</sup>) for soybean was 80 N + 60 P<sub>2</sub>O<sub>5</sub> + 80 K<sub>2</sub>O and for barley 120 N + 53 P<sub>2</sub>O<sub>5</sub> + 70 K<sub>2</sub>O. This study shows the response of soybean and winter barley to the applied fertilization.

Soybean (cultivar *Lucija* developed at the Agricultural Institute Osijek) was sown on 26<sup>th</sup> April 2010 by pneumatic sowing machine and harvested on 24<sup>th</sup> September 2010. From each basic plot an area of 2.0 m<sup>2</sup> of soybean crop was manually harvested, plants enumerated and pods separated from stem. Soybean plants were trashed by special combine. Grain of soybean was calculated on 13% grain moisture basis and realized plant density.

Winter barley (cultivar *Barun* developed at the Agricultural Institute Osijek) was sown by pneumatic sowing machine on 21<sup>th</sup> October 2012 and harvested on 22<sup>nd</sup> June 2013. From each basic plot barley ears were manually harvested from 4 x 0.25 m<sup>2</sup> (total 1.0 m<sup>2</sup>) area. The ears were enumerated and trashed by special combine. Grain of soybean and barley were calculated on a 13% grain moisture basis.

### *The sampling, chemical and statistical analysis*

Selection of soil for the experiment was made based on the previous soil test. The average soil sample was taken by the auger to 30 cm depth on October 27, 2007. The second soil sampling was made on September 24, 2010 after harvest of soybean from each basic plot. Protein and oil contents in soybean grain were determined by Near Infrared Transmittance spectroscopic method on Grain Analyzer (Infratec 1241, Foss Tecator) at the Agrochemical laboratory of the Agricultural Institute Osijek.

Data were statistically analyzed by ANOVA and treatment means were compared using t-test and

LSD at 5% and 1% probability levels.

Soil reaction and organic matter were determined according to ISO (1994, 1998). Mobile fraction P and K were extracted by AL-method (Egner et al., 1960), while Ca and Mg in the soil were extracted by acid solution (pH 4.65) of  $\text{NH}_4$ -acetate + EDTA (Lakanen and Ervio, 1971) and determined by ICP-AES.

Besides, another four stationary field trials were carried out with Fertdolomite application and the results were published in the previous studies. The first was identical as the above mentioned trial but with different crop rotation and was situated in Badljevina (25 km from Pavlovac in SE direction), site of Pakrac municipality (Kovacevic et al., 2015a, 2015b). The second trial was about 2 km away from the first experiment (Kovacevic et al., 2012) and the third trial was carried out in Gorjani, site of Osijek-Barannya County (Kovacevic et al., 2014b). The fourth trial was carried also carried out on the Kolar family farm in Pavlovac as a supplement to the trial with increasing rates of PK-fertilization because its 4-year effect was below expected (Rastija et al., 2006; Kovacevic et al., 2009): two replicates of the trial were limed with 10 t  $\text{ha}^{-1}$  of Fertdolomite and results of 5-year study were presented by Kovacevic et al., 2014a.

#### *The soil and weather conditions*

The experimental plot was selected based on the previous soil test. The soil is classified as stagnosol. Very acid reaction, moderate levels of available phosphorus, calcium and magnesium, averagely supply with potassium are main chemical properties of the soil (Table 1). Also, the high hydrolytical acidity was indication for liming.

For characterization of the weather condition during soybean and winter barley growing seasons, the meteorological data of Bjelovar Weather Bureau were used (SHS, 2013). Bjelovar is located 25 km as the crow flies northwest from the experiment site Pavlovac.

The 2010 growing season was characterized by excessive precipitation. Total precipitation in April-September period in Bjelovar was 834 mm or 80% higher compared to the 1961-1990 average. With that regard, precipitation in April and July were at the level of averages, while in May-June and August-September they were higher by 79% and 156%, respectively. Mean air temperature in the above mentioned period of 2010 was 18.0 °C or by 1.2 °C higher. With that regard, the highest difference in temperature level of 2.9 °C was recorded in July, while in April, August and September it was close to the long-term average (Fig. 1 and 2). Weather characteristics in 2010 were mainly favourable for soybean growth (Vrataric and Sudaric, 2008).

Table 1. Chemical properties of the soil surface layer to 30 cm depth

pH		%	mg 100 g <sup>-1</sup>		mg kg <sup>-1</sup>		cmol <sup>+</sup> kg <sup>-1</sup> Hydrolytical acidity
H <sub>2</sub> O	KCl		P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Ca	Mg	
4.73	3.90	2.31	12.6	34.1	629	111	5.12

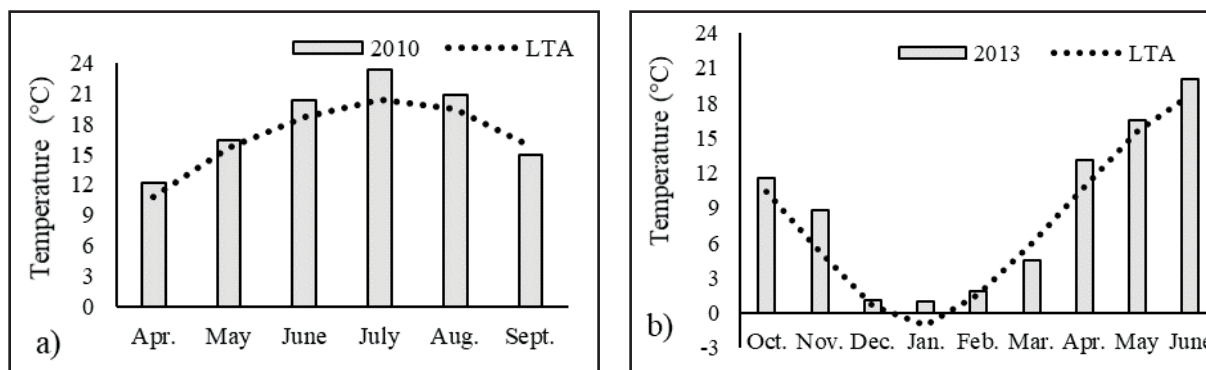


Figure 1. Average monthly air temperature (°C) in soybean growing season from April to September 2010 (a = left) in winter barley growing season from October 2012 to June 2013 (b = right) as compared to the long term average (LTA, 1961-1990) for Bjelovar (SHS, 2013)

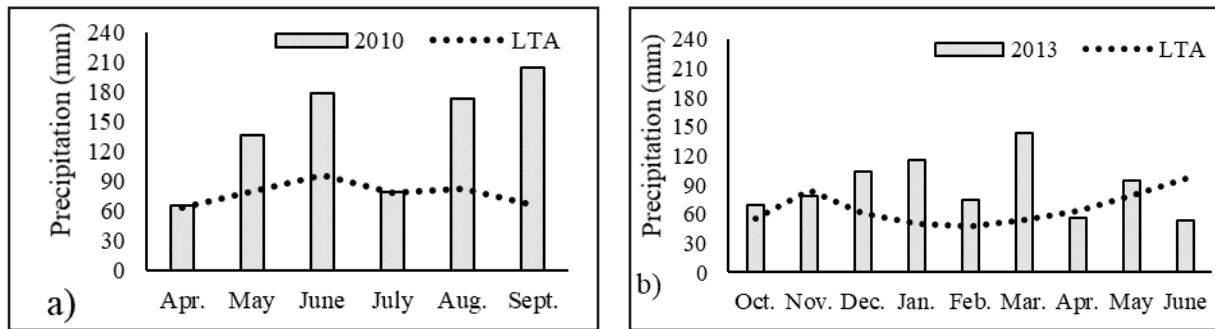


Figure 2. Average monthly precipitation (mm) in soybean growing season from April to September 2010 (a = left) in winter barley growing season from October 2012 to June 2013 (b = right) as compared to the long term average (LTA, 1961-1990) for Bjelovar (SHS, 2013)

Precipitation amount in the 2012/2013 growing season from October to June in Bjelovar was 790 mm or by one third higher than the average of 1961-1990 period. In the same period mean air temperature was 1.2 °C higher. Monthly distribution of precipitation was characterized by considerably higher values (total 439 mm) in December-March period or by 107% higher compared to the long-term average. In the remaining months these values were above but still close to averages with the exception of June when precipitation was lower by nearly 50% (Fig.1 and 2). Excessive precipitation during winter period was less favorable for barley growth, particularly under the less permeable and unreclaim soil conditions (Paunovic and Madic, 2011), for example in the soil of the experimental site. In general, the precipitation and temperature trends in the recent period are in accordance with the above mentioned global climate change.

**Results and discussion**

Table 2. Impact of Fertolomite application on soybean properties

Property*	Fertdolomite (13 <sup>th</sup> November 2007) amount (t ha <sup>-1</sup> )						LSD		
	0	5	10	20	30	40	Mean	5%	1%
Soybean properties (the 2010 growing season)									
Grain yield (kg ha <sup>-1</sup> )	4341 (100)	4352 (100)	4708 (108)	5040 (116)	5179 (119)	5361 (123)	4830	330	456
Plant density (thousand plants ha <sup>-1</sup> )	655.0 (100)	635.0 (97)	625.0 (95)	612.5 (93)	602.5 (92)	565.0 (86)	615.8	59.1	73,9
Thousand grain weight (g)	192.6 (100)	188.0 (98)	187.8 (98)	193.5 (100)	193.5 (100)	192.1 (100)	191.3	ns	
Protein in grain (%)	36.98 (100)	38.42 (104)	38.46 (104)	38.92 (105)	38.72 (105)	38.23 (103)	38.29	1.44	ns
Oil in grain (%)	23.59 (100)	23.29 (99)	23.38 (99)	23.42 (99)	23.25 (99)	23.47 (99)	23.40	ns	

\*in the brackets: index (the control = 100)

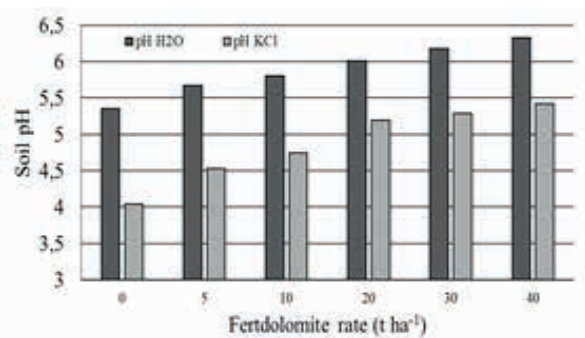


Figure 3. The impact of fertdolomite (t ha<sup>-1</sup>) on soil pH (0-30 cm depth, in October 2010). Error bars that represent the 95% confidence interval of a mean

Liming with Fertdolomite considerably affected on soil pH from 5.35 (pH in H<sub>2</sub>O) and 4.04 (pH in KCl) on the control treatment to 6.33 and 5.42, respectively, after application the highest rate of lime (Fig. 3).

Average grain yield of soybean in the experiment was 4830 kg ha<sup>-1</sup> with variation among the treatments from 4341 to 5361 kg ha<sup>-1</sup>, for the control and application the highest rate



Table 3. Impact of Fertolomite application on winter barley status

Property	Fertdolomite (13 <sup>th</sup> November 2007) amount (t ha <sup>-1</sup> )						Mean	LSD	
	0	5	10	20	30	40		5%	1%
	Winter barley status (the 2013 growing season)								
Grain yield kg ha <sup>-1</sup>	3190 (100)	3420 (107)	3840 (120)	4280 (134)	3490 (109)	3550 (111)	3630	640	832
ED per square m	408 (100)	442 (108)	488 (120)	590 (145)	530 (130)	502 (123)	493	74	93
TGW g	44.5 (100)	45.0 (101)	43.1 (97)	41.8 (94)	42.1 (95)	41.0 (92)	42.9	2.8	ns
HM kg	65.2 (100)	66.3 (102)	65.4 (100)	65.5 (100)	65.8 (101)	65.1 (100)	65.5	ns	

\* ED (ears density),. TGW (thousand grain weight), HM (hectoliter mass)

of Fertdolomite, respectively (Table 2). The application of Fertdolomite in autumn 2007 resulted in a significant increase in grain yields of soybean in the 2010 growing season up to 23% compared to the control. With that regard, for a significant increase in yield at the levels of 95% and 99%, rates of 10 t ha<sup>-1</sup> and 20 t ha<sup>-1</sup> of Fertdolomite, respectively, were needed. Yield increases by the application of these two rates of Fertdolomite were 8% and 16%, respectively.

By increasing the rate of Fertolomite to 30 and 40 t ha<sup>-1</sup> the yields of soybeans were additionally increased compared to the level of 20 t ha<sup>-1</sup> of applied Fertdolomite but these increases were non-significant (Table 3). Increasing rates of Fertdolomite had a negative effect on plant density realization (PDR) but significant difference and PDR decrease by 14% compared to the control were found only in the application of the highest Fertdolomite rate. Fertdolomite application had a moderate effect on protein contents in soybean grain. With that regard, the application of Fertdolomite in the amounts of 20 and 30 t ha<sup>-1</sup> caused a significant increase in protein content amounting 1.94% and 1.74% compared to the control, while the application of the highest rate of Fertdolomite caused a decrease in protein content to non-significant level relative to the control. Thousand grain weight and oil content in soybean grain were independent of Fertdolomite application (Table 2).

Grain yields of winter barley in the experiment was 3630 kg ha<sup>-1</sup> and it is low compared to yield potential of high-yielding *Barun* cultivar.

Yield variation among the applied treatments ranged from 3190 (the control) to 3840 (20 t ha<sup>-1</sup> Fertdolomite) kg ha<sup>-1</sup> (Table 3). Main reasons of low yield were too low plant density and ears density (average 493 ears per square meter) of barley crop. This barley status is probably a result of excessive precipitation during the winter period (Fig. 2) under less permeable and unreclaim soil conditions of the experiment site.

As in case with soybean three years ago, for a significant increase in yields of barley in the 2013 growing season to the level of 95% and 99% probabilities, the rates of 10 t ha<sup>-1</sup> and 20 t ha<sup>-1</sup> of Fertdolomite, respectively, were needed.

Yield increases of barley by the application these two rates of Fertdolomite were considerably higher than in soybean, 20% and 34%, respectively. By increasing the rates of Fertolomite to 30 and 40 t ha<sup>-1</sup> the yields of barley decreased to the level of non-significant differences related to the control. Ear densities per unit area were significantly increased to a maximum of 590 ears per m<sup>2</sup> by the application 10 and more tones of Fertdolomite ha<sup>-1</sup>. With that regard, increases compared to the control were 20%, 45%, 30% and 23%, for the treatments with 10, 20, 30 and 40 t ha<sup>-1</sup>, respectively.

Regarding thousand grain weight (TGW), a decreasing trend from 44.5 g to 41.0 g with increased Fertdolomite rates was found, but only with significant difference and by 8% lower value in the highest rate of applied Fertdolomite. Values of hectoliter mass were 65.5 kg on the average and independent of applied treatments.

In the study of the identical field experiment on Badljevina, acid soil crop rotation was as follows: maize (2008) – spring barley (2009) – maize (2010 and 2011) – wheat (2012) – maize (2013). Response of maize was specific in the tested four growing seasons. Significant yield reductions were found in the application of the highest rate of Fertilizer (for 7%, 10% and 14%, for 2008, 2010 and 2011, respectively), while in 2013 in the application of 20 – 40 t ha<sup>-1</sup> rates, yields of maize were increased by up to 16% compared to the control. Yield increases by Fertilizer were 10% on the average in 2010 and 2011 growing seasons with the application of 5 - 30 t ha<sup>-1</sup> (2010) and 5 - 10 t ha<sup>-1</sup> rates (2011), respectively. The lower rates of Fertilizer in the amount of 5 and 10 t ha<sup>-1</sup> were sufficient for the increase in yields of spring barley in 2009 by 22% and 14%, respectively, while the application of the higher rates caused yields to reduce to the level of the control. However, yields of wheat in 2012 were similar in all treatments with the exception of a slight reduction by 7% under the application of the highest rate of Fertilizer (Kovacevic et al., 2015a, 2015b).

In the second experiment in Badljevina, rates of 5, 10, 20 and 40 t ha<sup>-1</sup> of Fertilizer and crop sequence maize (2009) – wheat (2010) – winter barley (2011) were applied. With that regard, yield reduction by 10% by using the highest rate (maize) and yield increase by 10% by using the 5 and 10 t ha<sup>-1</sup> rates (wheat) were found. However, yields of barley were increased by 25% and 50% by using the 20 and 40 t ha<sup>-1</sup> rates, respectively (Kovacevic et al., 2012).

By the second experiment with Fertilizer in the amount of 10 t ha<sup>-1</sup> on the Kolar Family Farm in a 5-year period from 2008 to 2012, a moderate response of maize in three growing seasons (yield increases less than 10%) was recorded, yields of wheat were similar to the control, while only soybean responded by a considerable yield increase of 17%. Response of maize to liming was mainly moderate probably because of the other limitations of the soil fertility, for example unregulated air-water relations and low humus contents (Kovacevic et al., 2014a).

The field experiment with application of three rates of Fertilizer (3.5, 7.0 and 14.0 t ha<sup>-1</sup>) and the control started in the autumn of 2011 in Gorjani (Osijek-Baranya County) on acid soil for maize (2012) – wheat (2013) rotation. Yield of maize on the control was only 1.41 t ha<sup>-1</sup> and barren plants 73% as affected by drought and high temperature stress in flowering stage, while on the 14 t ha<sup>-1</sup> treatments yield increased to the level of 4.51 t ha<sup>-1</sup> and barren plants reduced to the 60% level. Influenced by Fertilizer yields of wheat were significantly increased by 22% (8.47 t ha<sup>-1</sup>) and 14% by using 7.0 and 14.0 t ha<sup>-1</sup> rates (Kovacevic et al., 2014b).

Increases in yields of both soybean and barley in our investigations could be explained primarily by the correction of soil acidity by liming. In acidic soil areas especially, when the pH drops below 4.5 the highly soluble toxic metals like aluminum (Al) are predominant in a soil solution. As a result, the concentration and supply of most basic plant nutrients become limited (Eduardo et al., 2005). Liming of acid soils may often increase the plant uptake of P by reducing the amounts of soluble Al rather than any direct effects on P availability (Curtin and Syers, 2001).

To reach their full potential, soybean grows best on soils of medium to high fertility with favorable soil pH. Besides that, soybean as a legume crop needs neutral pH reaction for nodules development. The optimum soil pH for soybean growth is 6.8, and the critical value ranges from 4.0 to 5.5 (Follet et al., 1981). Economic yield reductions due to soil acidity generally occur on sandy and silt loam soils at pH values less than 5.5. If soil pH values are 5.0 or less, liming should take priority over P and K fertilization. Soybeans may tolerate pH values as low as 5.2 on many alluvial clayey soils without significant yield loss (Slaton et al., 2017).

Tolerance to acid soils differs greatly among cereal species, and barley is usually considered the most susceptible crop (Garvin and Carver, 2003; Zhu et al., 2003; Wang et al., 2006; Paunovic and Madic, 2011). This fact could be used as an explanation for the very friendly response of barely to the applied treatment in our study. Komljenovic et

al., (2015) tested effects of liming with 10 t ha<sup>-1</sup> of hydrated lime and phosphorus fertilization by monoammonium phosphate to 1500 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> on maize yield in northern Bosnia for maize in monoculture. Influenced by liming, yield (4-year mean) of maize was increased by 31%, while P effect was considerably lower (6.14 and 6.65 t ha<sup>-1</sup>, for the control and average of ameliorative P treatments, respectively).

## Conclusion

In our study, application of Fertdolomite resulted in a considerable yield increase of soybean and barley and these responses were mainly more expressed compared to the response of maize and wheat in our other similar investigations. Response of soybean and barley to Fertdolomite

was specific because the yield of soybean continuously increased to 23% under the maximum applied rate, while for the increase in barley yield by 34% the rate of 20 t ha<sup>-1</sup> was appropriate. By additionally increasing Fertdolomite rates to 30 and 40 t ha<sup>-1</sup>, yields of barley were reduced to the control level.

Weather conditions also considerably affected the level of yields. Particularly low yields of barley were found as affected by plant density reduction due to extreme oversupply of precipitation in the winter and early spring periods. Extreme weather conditions are more frequent in the recent period as a result of climate change. With that regard, Fertdolomite application contributed to the alleviation of biotic stress induced by unfavorable weather conditions.

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