Response of soybean and barley to Fertdolomite application on acid soil

Vlado KOVACEVIC - Manda ANTUNOVIC - Ivana VARGA - Dario ILJKIC -Jurica JOVIC

Faculty of Agriculture of University J. J. Strossmayer in Osijek, V. Preloga 1, 31000 Osijek, Croatia;
E-mail: vlado.kovacevic@pfos.hr

Abstract: The stationary field experiment with the application of granulated dolomite ($MgCO_3$ x $CaCO_3$) enriched with nitrogen, phosphorus and potassium (Fertdolomite: 24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 % P_2O_5 + 3.0 % K_2O) in rates 0, 5, 10, 20, 30 and 40 t ha^{-1} on standard fertilization was started on 13th 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^2). 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^{-1} with variation among the treatments ranging from 4341 to 5361 kg ha^{-1}. At the rates 10 t ha^{-1} and 20 t ha^{-1} 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^{-1}), mainly due to low ears density (average 493 per m^2) 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^{-1} of Fertdolomite, yields of barley were significantly increased by 20% and 34%, respectively. However, the rates of 40 t ha^{-1} showed a non-significant difference of the barley yield as compared to the control level. The ear densities were significantly increased by application ≥ 10 t ha^{-1} 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.,

DOI: 10.18380/SZIE.COLUM.2017.4.2.7

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 Fertdolomite: 24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 % P_2O_5 + 3.0 % K_2O) started on 13th November 2007 on the Kolar Family Farm in Pavlovac (municipality Veliki Grdjevac, Bjelovar-Bilogora County). Fertdolomite was applied on the standard fertilization in the amounts of 0 (the control), 5 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1} and 40 t ha^{-1}.

The experiment was conducted by randomized block design in four replicates (basic plot 40 m^2). After the distribution of NPK 7:20:30 fertilizer (500 kg ha^{-1}) and Fertdolomite 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 Fertdolomite 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^{-1}) for soybean was 80 N + 60 P_2O_5 + 80 K_2O and for barley 120 N + 53 P_2O_5 + 70 K_2O. 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 26th April 2010 by pneumatic sowing machine and harvested on 24th September 2010. From each basic plot an area of 2.0 m^2 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 21th October 2012 and harvested on 22nd June 2013. From each basic plot barley ears were manually harvested from 4 x 0.25 m^2 (total 1.0 m^2) 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

 DOI: 10.18380/SZIE.COLUM.2017.4.2.7

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 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 pf 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 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 hydrolitical 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^{-1}		mg kg^{-1}		$cmol^+ kg^{-1}$
H_2O	KCl	Org. matter	P_2O_5	K_2O	Ca	Mg	Hydrolitical acidity
4.73	3.90	2.31	12.6	34.1	629	111	5.12

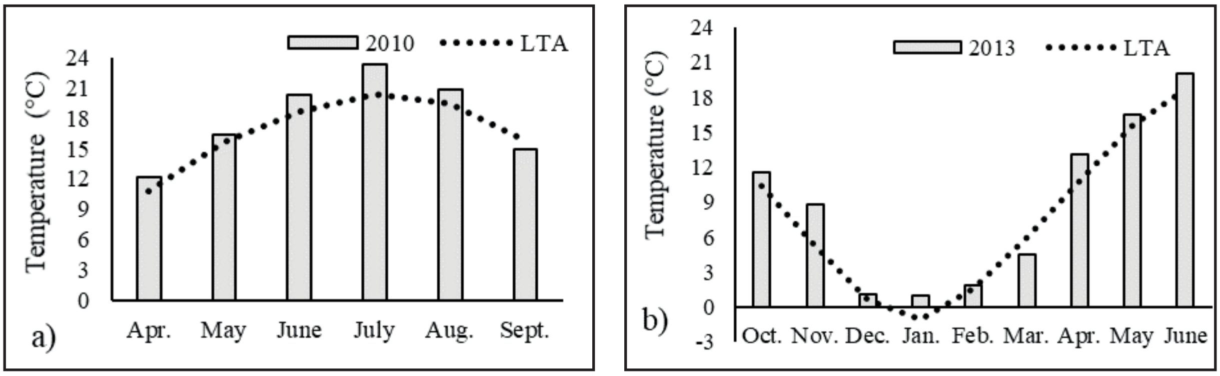

Figure 1. Average monthly air temperature (°C) in soybean growing season from April to September 2010 (a = left) in winter barley growing season from October 2012 to June 2013 (b = right) as compared to the long term average (LTA, 1961-1990) for Bjelovar (SHS, 2013)

DOI: 10.18380/SZIE.COLUM.2017.4.2.7

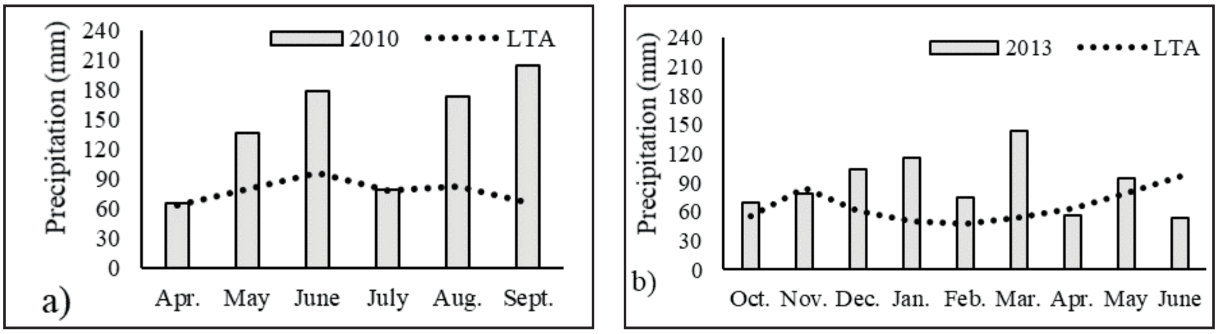

Figure 2. Average monthly precipitation (mm) in soybean growing season from April to September 2010 (a = left) in winter barley growing season from October 2012 to June 20132013 (b = right) as compared to the long term average (LTA, 1961-1990) for Bjelovar (SHS, 2013)

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.

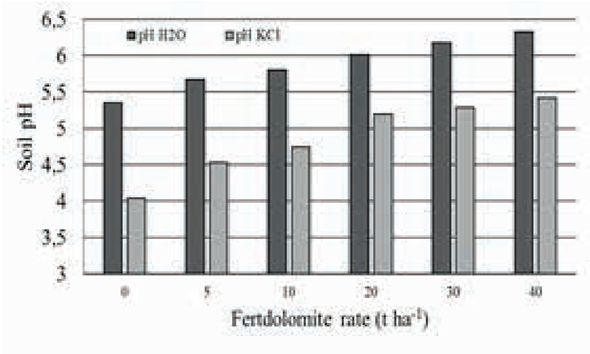

Figure 3. The impact of fertdolomite (t ha^{-1}) on soil pH (0-30 cm depth, in October 2010). Error bars that represent the 95% confidence interval of a mean

Liming with Fertdolomite considerably affected on soil pH from 5.35 (pH in H_2O) 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).

Results and discussion

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

Table 2. Impact of Fertolomite application on soybean properties

Property*	Fertdolomite (13th November 2007) amount (t ha^{-1})							LSD	
	0	5	10	20	30	40	Mean	5%	1%
	Soybean properties (the 2010 growing season)								
Grain yield (kg ha^{-1})	4341 (100)	4352 (100)	4708 (108)	5040 (116)	5179 (119)	5361 (123)	4830	330	456
Plant density (thousand plants ha^{-1})	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)

 DOI: 10.18380/SZIE.COLUM.2017.4.2.7

Table 3. Impact of Fertolomite application on winter barley status

Property	Fertdolomite (13th November 2007) amount (t ha^{-1})							LSD	
	0	5	10	20	30	40	Mean	5%	1%
	Winter barley status (the 2013 growing season)								
Grain yield kg ha^{-1}	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^{-1} and 20 t ha^{-1} 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^{-1} the yields of soybeans were additionally increased compared to the level of 20 t ha^{-1} 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^{-1} [1] 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^{-1} 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^{-1} Fertdolomite) kg ha^{-1} (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^{-1} and 20 t ha^{-1} 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^{-1} 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^2 by the application 10 and more tones of Fertdolomite ha^{-1}. 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^{-1}, 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.

DOI: 10.18380/SZIE.COLUM.2017.4.2.7

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 Fertdolomite (for 7%, 10% and 14%, for 2008, 2010 and 2011, respectively), while in 2013 in the application of 20 – 40 t ha^{-1} rates, yields of maize were increased by up to 16% compared to the control. Yield increases by Fertdolomite were 10% on the average in 2010 and 2011 growing seasons with the application of 5 - 30 t ha^{-1} (2010) and 5 - 10 t ha^{-1} rates (2011), respectively. The lower rates of Fertdolomite in the amount of 5 and 10 t ha^{-1} 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 Fertdolomite (Kovacevic et al., 2015a, 2015b).

In the second experiment in Badljevina, rates of 5, 10, 20 and 40 t ha^{-1} of Fertdolomite 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^{-1} rates (wheat) were found. However, yields of barley were increased by 25% and 50% by using the 20 and 40 t ha^{-1} rates, respectively (Kovacevic et al., 2012).

By the second experiment with Fertdolomite in the amount of 10 t ha^{-1} 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 Fertdolomite (3.5, 7.0 and 14.0t ha^{-1}) and the control started in the autumn of 2011 in Gorjani (Osijek-Barannya County) on acid soil for maize (2012) – wheat (2013) rotation. Yield of maize on the control was only 1.41 t ha^{-1} and barren plants 73% as affected by drought and high temperature stress in flowering stage, while on the 14 t ha^{-1} treatments yield increased to the level of 4.51 t ha^{-1} and barren plants reduced to the 60% level. Influenced by Fertdolomite yields of wheat were significantly increased by 22% (8.47 t ha^{-1}) and 14% by using 7.0 and 14.0 t ha^{-1} 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

 DOI: 10.18380/SZIE.COLUM.2017.4.2.7

al., (2015) tested effects of liming with 10 tha^{-1} of hydrated lime and phosphorus fertilization by monoammonuim phosphate to 1500 kg P_2O_5 ha^{-1} 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^{-1}, 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^{-1} was appropriate By additionally increasing Fertdolomite rates to 30 and 40 t ha^{-} , 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.

References

Antunovic, M., Kovacevic, V., Varga, I. (2014): Subsequent effects of liming with carbocalk on maize grain yields. Poljoprivreda/Agriculture **20** (2): 12-18.

Bogunovic, I., Kisic I., Mesic, M., Zgorelec, Z., Percin, A., Pereira, P. (2016): Application of spatial methods to identify areas with lime requirement in eastern Croatia. GU General Assembly 2016, held 17-22 April, 2016 in Vienna Austria, p.702. (http://adsabs.harvard.edu/abs/2016EGUGA..18..702B)

Bogunovic, M., Vidacek, Z., Racz, Z., Husnjak, S., Sraka M. (1997): Purposed soil map of Croatia and its usage. Agronomski glasnik **5-6**, Zagreb (in Croatian); see also:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.412.9258&rep=rep1&type=pdf

Bootsma, A., Gameda, S., McKenney, D. W. (2005): Potential impacts of climate change on corn, soybeans and barley yields in Atlantic Canada. Canadian Journal of Soil Science, **85** (2): 345-357.

Cindric, K., M. Gajic-Capka, M., Zaninovic, K. (2009): Observed climate changes in Croatia. In: Fifth National Communication of the Republic of Croatia under the United Nation Framework Convention on the Climate Change (UNFCCC) – selected chapters, Meteorological and Hydrological Service of Croatia, Zagreb. p.1-17.

Curtin, D., Syres, J.K. (2001): Lime-induced changes in indices of soil phosphate availability, Soil Science Society of American Journal **65**, 147–152.

Egner, H., Riehm, H., Domingo, W. R. (1960): Investigations on the chemical soil analysis as a basis for assessing the soil nutrient status II. Chemical extraction methods for phosphorus and potassium determination. Kungliga Lantbrukshügskolans Annaler **26**: 199-215.

Follet, R.H., Murphy L. S., Donahue, R.L. (1981): Fertilizers and soil amendments. London: Prentice Hall, Inc.. pp. 393-422.

Garvin, D.F., Carver, B.F. (2003): The Role of the Genotype in Tolerance to Acidity and Aluminum Toxicity. In: Rengel, Z. (Ed.), Handbook of Soil Acidity. Marcel Dekker, New York, p.387-406.

ISO. (1994): Soil quality – Pretreatment of samples for physico-chemical analyses. [ISO 11464:

1994(E)]. Geneva, Switzerland: International Organization for Standardization.

ISO (1998): Soil quality. Determination of organic carbon by sulfochromic oxidation. ISO 14235:1998.

Jolankai, M., Birkas, M. (2013): Precipitation impacts on yield quantity and quality of wheat crop. In: Proceedings, of the 48th Croatian & 8th International Symposium on Agriculture 17.-22. February 2013 Dubrovnik (Maric S. and Loncaric Z. Editors), Faculty of Agriculture, University J.J. Strosmayer in Osijek, p. 489-493.

Komljenovic, I., Markovic, M., Djurasinovic, G., Kovacevic, V. (2015): Response of maize to liming and phosphorus fertilization with emphasis on weather properties effects. Columella - Journal of Agricultural and Environmental Sciences **2** (1): 29-35.

Kovacevic V., Kadar I., Jolankai M., Rastija M. (2009): Influences of planosol fertilization with P and K on field crop yields and soil status. In: Plant-Soil Interactions at Low pH: A nutriomic Approach – Proceedings of the 7th International symposium at low pH (May 17 – 21, 2009, Guangzhou, China: Editors in Chief: Hong Liao, Xiaolong Yan, Leon Kochian), South China University of Technology Press Guangzhoun, p. 231-232.

Kovacevic, V., Rastija, M., Iljkic, D., Brkic, I., Kovacevic, J. (2015a): Response of maize and barley to liming with Fertdolomite. Poljoprivreda / Agriculture **21** (2): 30-35.

Kovacevic, V., Rastija, M., Iljkic, D., Markovic, M., Varga, I. (2014a): Impact of liming with Fertdolomite on grain yield of field crops. In: Book of Proceedings - Fifth International Scientific Agricultural Symposium Agrosym 2014, (Kovacevic, D. Editor), University of East Sarajevo, Faculty of Agriculture, Republic of Srpska, Bosnia, University of Belgrade, Faculty of Agriculture, Serbia, Balkan Environmental Association, B.EN.A, Greece et al. p. 123-127 (http://www.agrosym.rs.ba/agrosym/agrosym_2014/index.html).

Kovacevic, V., Rastija, D., Loncaric, Z., Sudar, R. (2012): Improvement of acid soil and field crops yield by liming with Fertdolomite. In: Compedium of Abstracts, 8th International Symposium on PSILPH (Plant-Soil Interactions at Low pH) 2012, 18-22. Oct. 2012. Bengaluru, India, (Editors Prakash N. B. et al.), Univ. of Agricultural Sciences, Bengaluru. p. 206-207.

Kovacevic, V., Rastija, M., Sudar, R., Iljkic, D., Varga, I. (2015b): Response of maize and wheat to Fertdolomite application. Columella - Journal of Agricultural and Environmental Sciences. **2** (1): 19-25.

Kovacevic, V., Seput, M., Pribanic, M., Iljkic, D. (2014b): Impacts of liming with Fertdolomite on maize and wheat yields. In: Factors influencing soil and landscape use in less favoured areas (Editors: Kotorova, D., Kovac, L., Soltysova, B.). Proceedings of manuscripts from scientific conference with international participation, May 14-15 2014, Zemplínska sirava, Penzion Terasa, Slovenská Republika. Narodne poľnohospodarske a potravinarske centrum –Vyskumny ustav agroekologie Michalovce (ISBN 978-80-971644-0-9; EAN 9788097164409), p. 103-106.

Lesk, C., Rowhani, P., Ramankutty, N. (2016): Influence of extreme weather disasters on global crop production. Nature **529**: 84-87.

Lobell, D., Field, C. (2007): Global scale climate–crop yield relationships and the impacts of recent warming. Public Health Resources. Paper 1 (http://digitalcommons.unl.edu/publichealthresources/152).

Lobell, D. B., Cahill, K. N., Field, C. B. (2007): Historical effects of temperature and precipitation on California crop yields. Clim. Change **81**, 187–203.

Lokya, T., Mishra, A., Ravinder, J., Shivhare, S., Mali, S. (2017): Influence of Integrated Nutrient Management Practices on Biomass Yield and Growth of Maize Crop in Acid Soil. Int. J. Curr. Microbiol. App. Sci (2017) 6(9): 1429-1435. doi: https://doi.org/10.20546/ijcmas.2017.609.173

Magas, D. 2013. Geography of Croatia. Library Geographia Croatica, Book 47 (1st edition). University of Zadar, Department of Geography and Publishing House Meridijan Zadar (in Croatian).

Mesic, M., Husnjak, S., Basic, F., Kisic, I., Gaspar, I. (2009): Superfluous acidity as negative factor of agriculture development in Croatia. Proceedings of 44th Croatian and 4th International Symposium on Agriculture (Maric S. and Loncaric Z. Editors.), 16th – 20th Febraury 2009, Opatija; Faculty of Agriculture Osijek, p. 9-18 (in Croatian).

Osborne, T. M., Wheeler, T. R. (2013): Evidence for a climate signal in trends of global crop yield variability over the past 50 years. Environ. Res. Lett. **8**, 024001.

 DOI: 10.18380/SZIE.COLUM.2017.4.2.7

Paunovic, S. A., Madic, M. R. (2011): Barley (University Textbook), University of Kragujevac, Faculty of Agronomy Cacak, Serbia (in Serbian).

Parry, M., C. Rosenzwei C., Livermore, M. (2005): Climate change, global food supply and risk of hunger. Phil. Trans. R. Soc. B **360**: 2125–38.

Rastija, M., Kovacevic, V., Vrataric, M., Sudaric, A., Krizmanic, M. (2006): Response of maize and soybeans to ameliorative fertilization in Bjelovar-Bilogora county. Cereal Research Communications **34** (1): 641-644.

Rosenzweig, C., Tubiello, F. N., Goldberg, R., Mills, E., Bloomfield, J. (2002): Increased crop damage in the US from excess precipitation under climatic change. Glob. Environ. Change **12**: 197-202.

Sarkar, A.K., and Sharma, P.D. (2005): Managing Acid Soils for Enhancing Productivity. National Resourse Management Division (ICAR), New Delhi. pp.23.

Schlenker, W., Roberts, M. J. (2008): Estimating the impact of climate change on crop yields. The importance of nonlinear temperature effects. National Bureau of Economic Research, Massachusetts, USA. Working Paper 13799 http://www.nber.org/papers/w13799.

SHS (2013): Climatological Reports from 1961 to 1990, 2010 and 2013 - Bjelovar, The State Hydrometeorological Service, Zagreb.

Slaton, N., Roberts, T., Ross, J. (2017): Fertilization and Liming Practices. In: Arkansas Soybean Production Handbook Chapter 5. (https://www.uaex.edu/publications/pdf/mp197/chapter5.pdf).

Stojic, B., Kovacevic V., Seput M., Kaucic D., Mikoc, V. (2012): Maize yields variation among years as function of weather regimes and fertilization. Növénytermelés, **61**: 85-88.

Sumner, M.E., Noble, A.D. 2003. Soil acidification: The world story. In: Rengel. Z, (Eds.). Handbook of Soil Acidity, Marcel Dekker, New York. pp. 1-28

Tang, C., Rengel, Z., Diatloff, E., Gazey, C. (2003): Responses of wheat and barley to liming on sandy soil with subsoil acitity. Field Crops Research, **80**: 235–244.

Temesgen, D., Getachew A., Ayalew, A., Tolessa, D., Julian G.J. (2017): Effect of lime and phosphorus fertilizer on acid soils and barley (*Hordeum vulgare* L.) performance in the central highlands of Ethiopia. Expl Agric. 53 (3): 432–444, Cambridge University Press 2016 (doi:10.1017/S0014479716000491).

UN (2017): Sustainable developments goals. 17 goals to transform our world. Goal 13: Take urgent action to combat climate change and its impacts. (http://www.un.org/sustainabledevelopment/climate-change-2/).

von Uexkull, H.R., Mutert, E. (1995): Global extent, development and economic impact of acid soils. In: Date RA, Grundon NJ, Raymet GE, Probert ME. eds. Plant–Soil Interactions at Low pH: Principles and Management. Dordrecht, The Netherlands: Kluwer Academic Publishers, 5–19.

Vrataric, M., Sudaric, A. (2008): Soybean *Glycine max* (L.) Merr., Agricultural Institute Osijek (in Croatian).

Wang, J., Raman, H., Zhang, G., Medham, N., Zhou, M. (2006): Aluminium tolerance in barley (*Hordeum vulgare* L.): physiological mechanisms, genetics and screening methods. Journal of Zhejiang University SCIENCE B **7**(10):769-787.

Zhu, M.Y., Pana, J., Wanga, L., Gua, Q., Huangd, C. (2003): Mutation induced enhancement of Al tolerance in barley cell lines. Plant Sci., **164** (1):17-23. (doi:10.1016/S0168- 9452(02)00317-5).

Zipper, S. C., Qui, J., Kucharik, C. J. (2016): Drought effects on US maize and soybean production: spatiotemporal patterns and historical changes. Environ. Res. Lett. 11, 094021