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Long term effect of Fertdolomite on soil, maize and wheat status on acid soil of eastern Croatia

Dugogodišnji učinak Fertdolomita na status tla, kukuruza i pšenice na kiselom tlu istočne Hrvatske

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Abstract

Soil acidity is one of the most common problems in cultivating plants in the open field. Dolomite enriched with nitrogen, phosphorus and potassium (trade name Fertdolomite: 24% CaO + 16% MgO + 3% N + 2.5% P_2O_5 + 3% K_2O) was applied in autumn of 2011 in four rates (0 t*ha^{-1}, 3.56 t*ha^{-1}, 7.14 t*ha^{-1} and 14.25 t*ha^{-1}). Aim of this experiment was testing 5-year residual impact of Fertdolomit on acid soil on maize and winter wheat grain yield and quality, as well as on changes of soil properties. Five year after application, Fertdolomit has shown positive long-term effect on soil pH and hydrolytic acidity. Under Fertdolomit treatments, in 2012/2013 wheat yield was significantly increased by 22%, in 2014/2015 by 25% and in 2016/2017 by 32% in comparison with control treatment. Application of highest Fertdolomite rate significantly increased wheat grain quality (protein and wet gluten content) while impact on thousand grain weight, hectoliter mass and starch content were insignificant during all growing season. Response of maize to Fertdolomite application was considerably lower compared to wheat. Maize yield increased only for 11% in both tested years (2014 and 2016), without any significant difference for grain quality.

Keywords: Fertdolomite, grain quality, grain yield, liming, maize, wheat

Sažetak

Kiselost tla je jedan od najčešćih problema u uzgoju kultiviranog bilja na otvorenom. Dolomit obogaćen s dušikom, fosforom i kalijem (trgovački naziv Fertdolomit: 24% CaO + 16% MgO + 3% N + 2,5% P_2O_5 + 3% K_2O) je primjenjen u jesen 2011 u četiri tretmana (0 t*ha^{-1}, 3,56 t*ha^{-1}, 7,14 t*ha^{-1} i 14,25 t*ha^{-1}) na kiselom tlu istočne Hrvatske. Cilj istraživanja je bio utvrditi naknadni petogodišnji utjecaj Fertdolomita na status ozime pšenice i kukuruza kao i neka svojstva tla. Pet godina nakon primjene Fertdolomit je ostvario pozitivan učinak na pH tla i hidrolitičku kiselost. U vegetaciji 2012/2013 prinos pšenice je značajno povećan za 22%, u 2014/2015 za 25% i u 2016/2017 za čak 32% na tretmanima Fertdolomita u usporedbi s kontrolnim tretmanom. Nadalje, primjena Fertdolomita je značajno povećala i kvalitetu zrna pšenice (sadržaj proteina i vlažnog gluten) dok utjecaj na masu tisuću zrna, hektolitarsku masu i sadržaj škroba nije bio statistički opravdan niti u jednoj vegetacijskoj sezoni. Reakcija kukuruza na Fertdolomit je bila značajno manja u usporedbi s pšenicom. Prinos kukuruza u obje godine istraživanja (2014 i 2016) je povećan za 11% dok kvaliteta zrna nije bila pod značajnim utjecajem Fertdolomita.

Ključne riječi: Fertdolomit, kalcizacija, kukuruz, kvaliteta zrna, prinos zrna, pšenica

Introduction

Maize and winter wheat are most common field crops in plant production of Croatia. According to official statistical data (Croatian Bureau of Statistics, 2017) out of 860,126 ha of arable land in Croatia (5-y averages 2012-2016) maize and winter wheat cover 271,843 ha and 171,211 ha, respectively, or about 50% of arable land. Furthermore, maize, wheat and rice were dominant cereals in many parts of the developed and developing countries. Soil acidity, unfavorable weather conditions and unbalanced nutrient supply were main limiting factors of cereals yield and quality worldwide as well as in Croatia. These factors might have negative effect alone or in interactions with each other on field crops yield. Climate change is induced and accelerated by human activity and can pose a serious threat to mankind by reducing food production (Jug et al., 2018.). With that aspect, agriculture is the most vulnerable sector affected by this phenome. Generally, origin of soil acidity can be divided on natural (geogenic and pedogenic) and anthropogenic processes. In recent decades, human activities in intensive agricultural production accelerated soil acidification by applying excessive nitrogen fertilizers (NH_4^+ or NH_2-based fertilizers) in crop system (Guo et al., 2010; Schroder et al., 2011). It is well known that toxicity of aluminum (Al^{3+}), manganese (Mn^{2+}) and iron (Fe^{3+}) on the one hand and lack or inaccessibility elements such as phosphorus (P), calcium (Ca) and magnesium (Mg) on the other hand, are the main problems of acid soil (Mengel and Kirby, 2001). Aluminum toxicity and soil infertility restricts root and crop growth and phosphorus uptake (Rengel, 2003; Iqbal, 2012; Eimil-Fraga et al., 2016). Some authors estimated that 30% to 40% area had more or less acid reaction worldwide (Von Uexküll and Mutert, 1995; Hede et al., 2001; Noble and Sumner, 2003). According Mesić et al. (2009) in Croatia about 32% total agricultural surface is acidic with dominant soil type luvisol and stagnosol.

Lime, organic matter and fertilizers can reduce soil acidity and nutrient deficiency (Chao et al., 2014). Applying Ca is a very old and common agricultural practice, used for increasing productivity in acid agricultural soils. Usually the materials for liming were calcium oxide (CaO), calcium hydroxide ($Ca(OH)_2$), calcium carbonate ($CaCO_3$), calcium magnesium carbonate ($CaMg(CO_3)_2$) or some other calcium complex (Meriño-Gergichevich et al., 2010). However, some other materials can be used for decreasing soil acidity such as steel slag (Plopeanu et al., 2017), biochar (Berihun et al., 2017), wood ash and filter dust (Ivezić et al., 2017). Under environmental conditions of Croatia and Bosnia and Herzegovina the positive effects of liming on soil status, field crops yield and quality were found (Markovic et al., 2008; Andric et al., 2012; Kovačević et al., 2015). The similar results of positive effects of liming was shown by Wijanarko and Taufiq (2016), Quiroga et al. (2017), Shaaban et al. (2017) and others. Crusciol et al. (2017) reported that gypsum, limestone and silicate improve fertility throughout the soil profile which led to the greater profit.

The main aim of this study was to evaluate residual impact of Fertdolomite on soil properties, maize and winter wheat yields during five years with emphasis on grain quality parameters of wheat from the aspect of food industry needs.

Material and methods

Fertdolomite is a trade name of dolomite enriched with N, P and K (product of Petrokemija Fertilizer Factory in Kutina, Croatia) and consist 24% CaO, 16% MgO, 3% N, 2.5% P_2O_5 and 3% K_2O. The field experiment was set up in November 22, 2011 in Gorjani eastern part of Croatia (45°40'68'' N, 18°35'40'' E) on acid soil (pH_{KCl} 4.13; hydrolytic acidity 6.78 cmol*kg^{-1}) with total four rates of Fertdolomit (Table 1). The trial was conducted by randomized complete block design (RBCD) in four replicates with basic plot size: 112.5 m^2. The crop rotation consisted of winter wheat in 2012/2013, 2014/2015 and 2016/2017 and maize in 2014 and 2016. In all years standard fertilization and cultivation practices for winter wheat and maize were conducted.

Table 1. Quantities of nutrients added by Ferdolomite

Treatment (t*ha^{-1})	CaO (kg*ha^{-1})	MgO (kg*ha^{-1})	N (kg*ha^{-1})	P_2O_5 (kg*ha^{-1})	K_2O (kg*ha^{-1})
0	0	0	0	0	0
3.56	854	570	107	89	107
7.14	1,714	1,142	214	178	214
14.25	3,420	2,280	428	356	428

Four 11 m long rows of maize (30.8 m^2) were harvested manually from each basic plot for determination grain yield and other tested parameters. Mass of cob was weighed by precise electronic balance (Kern CH25K50) and grain yields were calculated on realized plant density and 14% grain moisture basis. Winter wheat ears of 1 m^2 (4 x 0.25 m^2) were harvested by shears, enumerated, dried on open and thrashed by special combine for small-field experiments. Yields were calculated on 13% grain moisture basis.

Sampling, chemical and statistical analysis

Soil samples were taken from the 30 cm depth soil layer five years after Fertdolomit application. Soil pH reaction in water and KCl was analyzed according ISO 10390 (International Organization for Standardization,1994), humus content according ISO 14235 (International Organization for Standardization, 1998) and phosphorus and potassium content by AL method according Egner et al. (1960). All chemical analysis was made in Agrochemical laboratory of Faculty of Agriculture in Osijek. Ten cobs of maize from each basic plot were used for determination of grain moisture at harvest and grain share in cob. Grain moisture was determined by electronic grain moisture instrument (WILE-55, Agroelectronics, Finland).

Entire mass of wheat grain (from 1 m^2 harvested area) was used as sample for determination of quality parameters. Quality parameters of wheat and maize grains were determined by Near Infrared Transmittance spectroscopic method on Grain Analyzer (Infratec 1241, Foss Tecator) in Agrochemical Laboratory of Agricultural Institute Osijek. Data was statistically analyzed by ANOVA and treatment means were compared using Student's t-test and least significant difference (LSD) at 0.05 probability levels.

Weather characteristics

For characterization of weather conditions, the meteorological data of Osijek Weather Bureau (about 30 km air-distance from Gorjani in NE direction) were used.

Generally, weather deviations as either drought or excessive precipitation in combination with either cold winter or high temperatures in spring are mainly in connection with lower yields of wheat (Pepó and Kovacevic, 2011; Jolánkai and Birkas, 2013; Majdančić et al., 2016). With aspect of wheat growing, three different years were observed in this experiment (Figure 1).

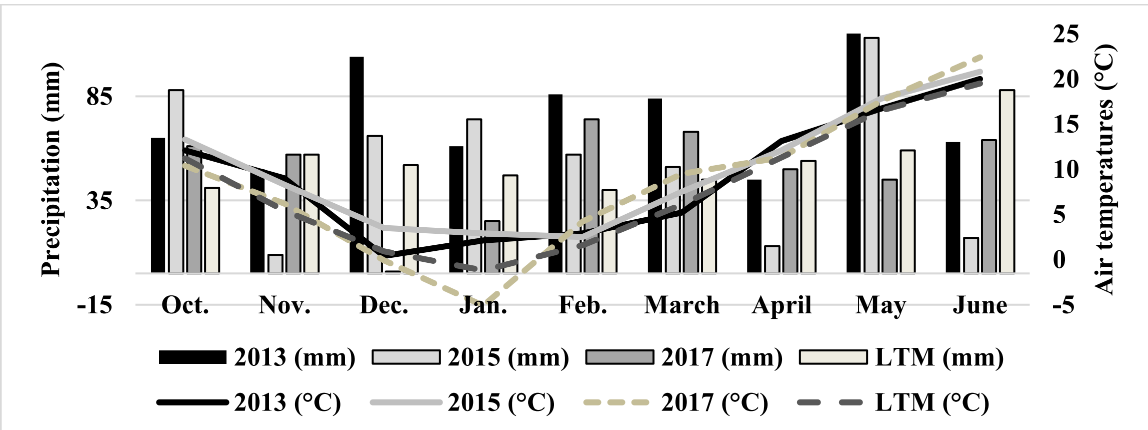

Figure 1. Precipitation and mean air-temperatures in Osijek during three wheat growing season (Meteorological and Hydrological Service of Croatia, 2017)

Precipitation close to 40% above the long term mean (LTM, 1961-1990) and air-temperature higher for 1.1 °C in comparison to the LTM characterized the 2012/2013 wheat growing season. Precipitation quantity in the 2014/2015 growing season were close to the wheat needs, while the mean air temperatures was for 2 °C higher as compare to the LTM (9.9 °C and 7.9 °C, respectively). In the 2016/2017 growing season precipitation quantity was less for 8% and air temperature was higher for 0.6 °C in comparison with LTM.

Generally, the lower annual yields of maize are in very close connection with water deficit and higher air-temperatures, particularly at summer months (Videnović et al., 2013). With that regard, the 2014 and 2016 growing season was very favorable for maize because of adequate and good monthly distribution of precipitation as well as the higher temperatures (Figure 2). In comparison with the LTM precipitation in April-September period was higher for 40% (2014) and for 16% (2016). At the same time, air-temperature was higher for 0.6 °C (2014) and for 1.1 °C (2016), respectively, as compare to the LTM.

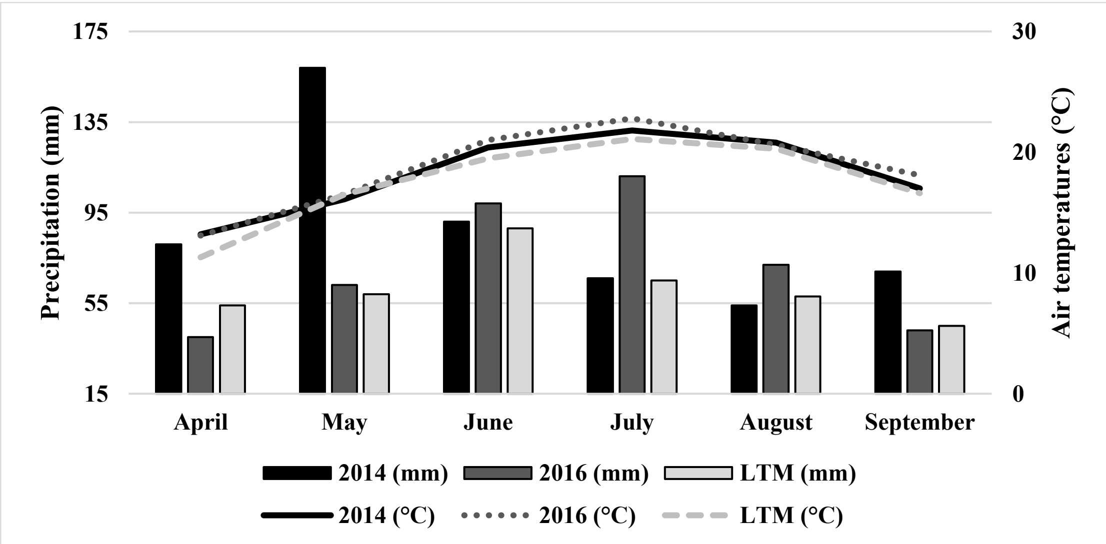

Figure 2. Precipitation and mean air-temperatures in Osijek during two maize growing seasons (Meteorological and Hydrological Service of Croatia, 2017)

Results and discussion

Soil status

Liming with Fertdolomit had a positive effect on some chemical properties of the soil five years after application (Figure 3). Average pH_{H2O} was 5.69 and pH_{KCl} 4.49 which was below optimum pH for maize and wheat production. However, the values of pH_{H2O} and pH_{KCl} increased from very acid reaction on control treatment (5.38 and 4.01, respectively) to acid reaction (6.01 and 5.09, respectively) under highest Fertdolomit treatment. Abdulaha-Al Baquy et al. (2017) concluded that critical values of soil pH_{H2O} for winter wheat varies from 4.66 to 5.29 depending of soil type. The authors conclude that plant height, shoot and root dry weight and chlorophyll content in leaves were significantly decreased below these critical soil pH. Furthermore, in this study, average value of hydrolytic acidity was 4.19 cmol*kg^{-1} with variation from 4.93 cmol*kg^{-1} (0 t*ha^{-1}) to 3.2 cmol*kg^{-1} (14.25 t*ha^{-1} Fertdolomit).

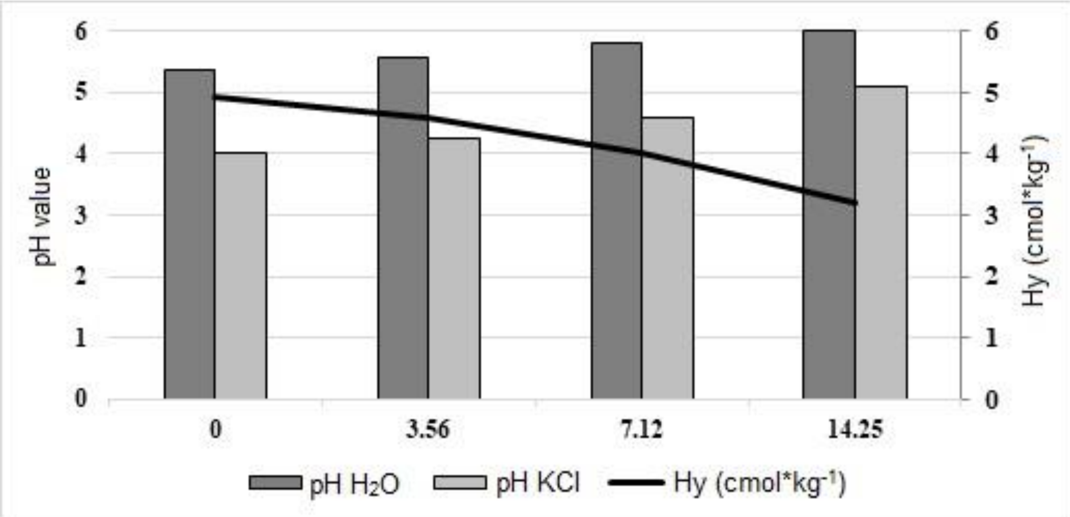

Figure 3. Residual liming effect on soil pH value and hydrolytic acidity (0-30 cm depth) five years after application

Winter wheat status

Generally, in all three vegetation periods of winter wheat residual effect of Fertdolomit was significant for yield and some other tested parameters (Table 2). In the 2012/2013 growing season, Fertdolomit increased winter wheat yield by 14% and 22% while, there were no significant differences in the ears number per m^2. Similar results were shown Kovačević et al. (2014). The 1,000 grain weight and hectoliter weight were quite similar for all treatments. Except yield, liming had also a significant impact on wheat quality parameters (Table 3). The highest Fertdolomit treatment increased protein and wet gluten content for 12% and 14%, respectively, which is also to be expected due to a positive correlation of these parameters (Horvat et al., 2013). All liming treatments were significant for yield and ears number per m^2 in the 2014/2015 growing season as fourth season after liming (Table 2). Fertdolomite application of 3.56 t*ha^{-1} increased the wheat grain yield by 13%. Moreover, the highest positive influence of Fertdolomit was at rate of 7.14 t*ha^{-1} where the yield was increased by 25% as compared to control. Further increment of Fertdolomit application to 14.25 t*ha^{-1} did not have additional influence on the increase of grain yield. This yield increment was mainly resulted with higher number of ears per unit area. Grain quality parameters of wheat in fourth season after application were significantly increased only by the highest Fertdolomit rate (Table 3). Protein and wet gluten content were statistically higher for 8%. Varga et al. (2007) found that milling and baking quality of wheat is mainly determined by the genetic basis, but it can be influenced by management practice.

In the 2016/2017 growing season wheat yield achieved the highest increment in the experiment up to 32% on the second treatment (7.14 t*ha^{-1}). The main reason for yield increase was significantly higher number of ears per m^2 up to 28% on this treatment. At the same time, residual effect of Fertdolomit on wheat quality parameters six years after the application was not significant (Table 2).

In addition to the positive effect of added CaO and MgO by Fertdolomit on maize and wheat yield and quality, the role of phosphorus (P) and potassium (K) was certainly important for the plant growth. Adequate P rate can result in higher grain production, improved crop quality, greater stalk strength, increased root growth and earlier crop maturity, while K has essential role for enzyme activation, stomatal activity, water and nutrient transport, photosynthesis, protein and starch synthesis (Bergmann, 1992; Salkic et al., 2016).

Table 2. Response of winter wheat yield and other yield components to Fertdolomite application during three vegetation periods

Fertdolomit ($t*ha^{-1}$)	Grain yield ($t*ha^{-1}$)	Ears per m^2	Thousand grain weight (g)	Hectoliter weight (kg)
		2012/2013		
0	6.93	692	39.9	80.7
3.56	7.27	732	40.8	81.5
7.14	8.47	758	40.3	81.7
14.25	7.9	760	40.5	81.3
Mean	7.64	736	40.4	81.3
$LSD_{0.05}$	0.87	ns	ns	ns
		2014/2015		
0	6.46	513	42.4	81.2
3.56	7.31	571	42.4	81.5
7.14	8.08	616	42	81.3
14.25	7.92	614	42.7	81.6
Mean	7.44	579	42.4	81.4
$LSD_{0.05}$	0.67	45	ns	ns
		2016/2017		
0	6.43	569	39.1	78.7
3.56	7.07	589	39.1	79.3
7.14	8.5	726	38.4	78.8
14.25	7.81	676	39.6	79.6
Mean	7.45	640	39.1	79.1
$LSD_{0.05}$	1.18	100	ns	ns

LSD – least significant difference; ns – not significant.

Table 3. Response of winter wheat quality parameters to Fertdolomite application during three vegetation periods

Fertdolomite ($t*ha^{-1}$)	Protein (%)	Starch (%)	Wet gluten (%)
	2012/2013		
0	10.2	72.2	24.7
3.56	11	71.6	27.2
7.14	11.1	71.6	27.6
14.25	11.4	71.1	28.2
Mean	10.8	71.7	26.9
$LSD_{0.05}$	0.8	ns	2.6
	2014/2015		
0	11.5	71.1	29.6
3.56	11.9	71.1	30.6
7.14	11.9	71.2	31.1
14.25	12.4	70.6	32.1
Mean	11.9	71	30.9
$LSD_{0.05}$	0.8	ns	2.2
	2016/2017		
0	10.9	72.5	26.9
3.56	11.1	72.6	27.2
7.14	11.3	72.4	27.7
14.25	11.2	72.5	28
Mean	11.1	72.5	27.4
$LSD_{0.05}$	ns	ns	ns

LSD – least significant difference; ns – not significant.

In addition to the influence of liming in this experiment, quality parameters were under considerable influence of growing season as well. The highest values of protein and wet gluten were achieved in the 2014/2015 season which had the highest average air temperatures and precipitation quantity in level of LTM. Jolankai and Birkas (2013) reported, based on the 15 years period of experiment, that wheat yield and quality were highly influenced by different crop years. Authors conclude that wet gluten content proved to be a most stable characteristic while protein and sedimentation values were more variable in relation with the precipitation of crop years. Horvat et al. (2012) for almost quality parameters reported a statistically significant differences among genotype (G), location (L) and year (Y) and their interactions.

Maize status

In both years grain yield of maize was relatively high (average: 12.2 t*ha^{-1}) in comparison with official statistical data for the Republic of Croatia (8.3 t*ha^{-1}, Croatian Bureau of Statistics, 2017) which was mainly caused by adequate and good distribution of precipitation, especially in the phase of maize flowering. However, the application of Ferdolomit resulted with a significant increase of maize yield for about 8%, 9% and 11% for the first, second and third treatment in the 2014 growing season (Table 4). With that regard, even the first treatment of 3.56 t*ha^{-1} of Fertdolomit was adequate for a significant yield increase but differences between the lowest and the highest rate were not significantly different. Joris et al. (2013) concluded that liming decrease soil acidity and consequently increases root length, shoot biomass and grain yield of maize. Other yield and quality components were not made in this growing season.

Residual effect of liming in 2016 growing season was also statistically justified with yield increase for 1.29 t*ha^{-1} or 11% (Table 4). Unexpectedly, only treatment with 3.56 t*ha^{-1} of Ferdolomit was significant. Absence of yield increase for the two other treatments could be the explained by the lower plant density in the experiment and some increase in the share of barren plants. Moreira et al. (2015) has shown that maximum grain yield was obtained with the application of 1 t*ha^{-1} of lime and 8 t*ha^{-1} of cattle manure. Authors considered that liming significantly increases soil pH, calcium concentrations in the soil and exchangeable magnesium and cation exchange capacity (CEC) of soil and reduces potential acidity. Apart from grain yield, liming did not show any statistically significant differences for other tested yield components and quality parameters for maize after five years of Fertdolomit application (Table 5).

Table 4. Response of maize status to Fertdolomite application in two growing seasons

Fertdolomit ($t*ha^{-1}$)	Grain yield ($t*ha^{-1}$)	Grain moisture (%)	RPD ($plants*ha^{-1}$)	BP (%)
		2014		
0	11.38	21.2	90	3.2
3.56	12.24	21.3	94	3
7.12	12.38	21.4	92	3.1
14.25	12.6	21.1	94	3
Average	12.15	21.2	93	3.1
$LSD_{0.05}$	0.65	ns	-	-
		2016		
0	11.68	23	88	1.1
3.56	12.97	22.7	87	1.6
7.12	12.16	21.7	80	0
14.25	12.23	22.7	83	5.7
Average	12.26	22.5	85	2.1
$LSD_{0.05}$	0.98	ns	-	-

RPD - realized plant density; BP - barren plants contribution; LSD – least significant difference; ns – not significant.

Table 5. Response of maize quality parameters to Fertdolomite application for 2016

Fertdolomit ($t*ha^{-1}$)	Thousand grain weight (g)	Hectoliter weight (kg)	Protein (%)	Starch (%)	Oil (%)
0	419	76	8	70.9	4.8
3.56	421	76.3	7.6	71	4.9
7.12	436	77	8.2	70.9	4.8
14.25	427	75.8	8.7	70.4	4.9
Average	426	75.8	8.7	70.8	4.9
$LSD_{0.05}$	ns	ns	ns	ns	ns

LSD – least significant difference; ns – not significant.

Conclusions

Fertdolomit application had significant positive long-term effect on cereals grain yield. However, response of wheat to Fertdolomite application was considerably better compare to maize because yields increased for 22% in 2012/2013, 25% in 2014/2015 and up to 32% in 2016/2017 growing season compare to control treatment. Simultaneously, maize grain yield increased only for 11% in 2014 and 2016 growing season. With aspect of wheat yield, the best treatment was 7.14 t*ha^{-1} of Fertdolomit in all three growing season and the additional increase of CaO did not shown any significance. On the other hand, the highest Fertdolomite rate (14.25 t*ha^{-1}) significantly increased grains protein and wet gluten content of wheat, while thousand grain weight, hectoliter mass and starch contents were independent on applied fertilization. Thus, application of Fertdolomite could be a potential option as liming material on the acid soil in addition to a source of P and K for crop production.

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