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Small Doses of Lime with Common Fertilizer Practices Improve Soil Characteristics and Foster the Sustainability of Maize Production

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Abstract: Lime application with other complementary sustainable management practices increases crop yield, but liming is modestly applied in Serbia. This study investigated the influence of liming (1000 kg/ha) combined with the common application of mineral fertilizers on maize yield and the chemical properties of Pseudogley soil. The experiment was conducted near Kraljevo, Western Serbia, on maize hybrid ZP 606, sown in a two-year monoculture. The experiment had three treatments: fertilizer, fertilizer+lime, and control treatment. The soil is acid, poor in humus, and contains an increased content of mobile aluminum. There was a significant increase in yield under the fertilizer and lime+fertilizer treatments, compared with the control. The yield of maize in the limed treatment was 4.4–9% higher than in the fertilizer treatment. The positive effects of liming on soil are related to an increase in pH, base saturation, and available phosphorus and a decrease in available aluminum. In the fertilizer treatment, there was a small decrease in pH and base saturation, whereas the amount of aluminum remained high, indicating that further application of fertilizers without lime can increase the aluminum content and foster its toxicity. The long-term sustainability of maize production in Serbia should include liming as a regular management practice on Pseudogley soil, with the utilization of smaller doses of lime because of the potential CO_2 effects. To improve soil health, food, and environmental security, and incorporate new crops, developing a framework promoting liming as a sustainable management practice is of high importance.

Keywords: liming; mineral fertilizers; food security; acid soil; maize

1. Introduction

In Serbia, one of the main threats to good agricultural productivity is soil acidity. Almost 15% of agricultural soil in Serbia is acidic (pH in water<5.5). The sustainable use of acid soil requires adequate nutrient inputs and soil amendments, such as lime, compost, manure, and biochar, to optimize crop nutrition and achieve sustainable crop production [1,2]. Naturally, processes of soil acidity refer to carbonic acid-triggered leaching of basic cations, weathering of acidic parent materials, decomposition of organic matter, and deposition of atmospheric gases [3,4]. Anthropogenic activities consider inappropriate use of acid-forming fertilizers and poor soil management. Long-term application of high rates of N fertilisers, loss of cations via leaching and removal [5], and continuous cropping without organic inputs are among the anthropogenic factors that increase soil acidity [6,7]. Low nutrient availability associated with soil acidity is a major constraint on crop production.

Maize (Zea Mays L.) grows well on neutral to mildly acidic soil, and liming can be used to control yield. The average maize yield in Serbia (2012–2021) is 6.3±1.6 t·ha^{-1} [8]. The high variation in yield is a consequence of rainfall patterns and other management and edaphic factors, such as soil fertility,

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lower nutrient availability, water–air regime in soil, smaller parcels, and less commercially oriented and dominantly rainfed production.

Liming is one of the most common practices to ameliorate acid soil, with many well-understood benefits. It causes the reduction of Al and Mn toxicity [9,10], maximizes nutrient availability for plants [11,12], decreases P immobilization [13], and improves physical [14] and biological soil quality [15], and finally, enhances crop production. Also, liming enhances C sequestration rate of both minerally fertilized and organically manured plots [16]. The effect of lime rates on soil chemical characteristics depends on lime type and particle size [10,17], soil buffering capacity, organic matter content [10], initial soil acidity, Ca and Mg contents, participation of cations in adsorptive complex, crop response to liming, crop management practices, and economic considerations [10,18]. Different liming materials (calcite, dolomite) are the most-used materials for acidity correction in Serbia, and soil pH and base saturation are mainly used for determination of lime doses. Lime is mainly used together with mineral fertilizers, and less with appropriate addition of manure, due to its deficiency.

Another important role of liming is its potential impact to climate change. In the contact of limestone and strong acids in the soil some of the limestone is degraded and C is released as CO_2. De Klein et al. [19] proposed the CO_2 emission coefficient of 0.12 Mg C per Mg for limestone, which indicates that 100% of C in $CaCO_3$ is eventually released to the atmosphere in the form of CO_2. This assumption appears unlikely because of the very low solubility of $CaCO_3$ and carbonate transport through soil [20]. Hijbek et al. [21] stated that lime application causes substantial greenhouse gas (GHG) emissions, whereas Holland et al. [15] stated that the impacts of liming are complex and that there are markedly different changes in emissions between different gases. In fact, liming material can act either as a net source or a net sink for carbon dioxide (CO_2) [22]. The IPCC statement creates a concern for policy makers and farmers regarding the optimal doses of lime for the amelioration of soil because excessive liming is obviously not environmentally friendly [23].

Sustainable soil management must consider all known benefits and constraints of liming. There is a lack of GHG emission measurements from agricultural activities in Serbia, and this study aimed to investigate the effect of small lime doses (1 $t \cdot ha^{-1}$) and common fertilizer doses on maize grown on Pseudogley soil in Western Serbia and to observe the changes in soil chemical characteristics in a short-term experiment.

2. Materials and Methods

2.1. Study Area

This study was conducted in the village Ratina, in Raška district, 7 km east from the city of Kraljevo, in the western part of Serbia. The dominant farming system of the district is rainfed farming of field crops for human and animal consumption. The average productivity of maize is lower compared with northern regions because of the challenges of low soil fertility, land shortage, smaller parcels, and lower investments. Tillage usually consists of fall plowing (depth 20–25–30 cm) and spring disking and harrowing, which are standard farming practices in Western Serbia [24].

Maize is dominantly grown in Western Serbia in river valleys and in old lacustrine sediment terraces above river valleys, which is the main zone of Pseudogley Soils in Serbia. Pseudogley Soils corresponds to reference soil groups of Planosols and less often to Stagnosols of the World Reference Base for Soil Resources [25]. These soils cover an area of approximately 500,000 ha in Serbia and about 32,000 ha in the Čačansko-Kraljevački basin, which is an important agricultural area in Western Serbia. There are no consistent data about the area of maize grown on Pseudogley Soils in this basin, as the information changes from year to year, but considering the number of cattle farms, especially those with dairy cows, it can be assumed that maize is grown on this type of soil at approximately 20,000 ha. Pseudogley Soils are characterized by lower fertility and weak soil water and physical characteristics. Despite this, the advantage of these soils is that they usually cover flat terrain or terrain with mild slopes and are easily accessible to agricultural machinery. Additionally, they are located in well-populated areas, and their agricultural significance is therefore very high. The acidic reaction of Pseudogley Soils, low humus content, and reduced availability of the most important

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plant nutrients, primarily phosphorus and calcium, are limiting factors for achieving higher maize yields. In addition to the acidic reaction, Pseudogley Soils of the Čačansko-Kraljevački basin are characterized by an increased content of aluminum, iron, and manganese, which adversely affect the cultivation of most field crops. Another very important constraint is the poor water–air regime of Pseudogley Soils. These soils have an impermeable heavy-textured subsurface layer characterized by stagnic properties and reducing conditions for some period of the year. When the impermeable Btg–horizon is located at a shallow depth, root growth is impeded, and maize yields vary greatly from year to year, depending mainly on the precipitation pattern. In Serbia, regular agricultural operations are applied to these soils, but the effects of ameliorative measures can improve soil properties and crop production to a much higher extent. Liming is recommended for improving acidity in Serbia, but wider agricultural production does not accept liming as a regular measure. In addition, there is no overall recommendation about which fertilizers and in what quantities must be used on these soils to ensure economically justified yields and avoid large fluctuations, especially in years with unfavorable meteorological conditions.

The climate of the study area is temperate, with mild winters and moderately dry summers. It is characterized by high rainfall variability during the vegetative season. The climate characteristics recorded during the experimental period are shown in Table 1. The rainfall amount in the vegetative period of the first season was much higher compared with the second season and was also higher than the multiannual averages. However, the second season was moderately humid, with a lack of serious dry spells.

Table 1. Climate characteristics at meteorological station Kraljevo (219 m a.s.l., 43° 43′ N, 20° 42′ E) during the two growing seasons.

Climate Characteristics	Month						
	Apr	May	June	July	Aug	Sept	Oct
First season – 2020							
T_{min} (°C)	4.2	10.5	14.4	15.5	16.3	12.8	8.2
T_{max} (°C)	19.7	21.7	25.3	28.4	29.0	26.7	19.8
Rainfall (mm)	36.9	84.4	147.3	127.7	117.7	7.5	101.9
Second season – 2021							
T_{min} (°C)	3.8	10.5	14.2	18.2	15.4	11.0	5.2
T_{max} (°C)	16.1	23.3	28.7	31.8	30.1	25.4	15.7
Rainfall (mm)	66.1	56.9	26.3	83.4	33.5	24.5	86.7

2.2. Soil Sampling and Laboratory Analysis

Soil was sampled in November 2019 and again in 2021 after the experiment was carried out to determine the physical and chemical characteristics. The soil is classified as moderately deep Pseudogley Soil. Soil samples to determine soil texture were collected from the open soil profile. The composite soil samples for determination of chemical characteristics were collected from 0–30 and 30–60 cm depths, before planting and after harvest, from five points using the crisscross sampling technique, and from each experimental plot. The particle size distribution was determined by combining the sieving and pipette methods [26], and the soil textural class was determined according to the USDA triangle. Soil pH values were measured potentiometrically in 1:2.5 soil:water and 1:2.5 soil:1 M KCl suspensions [26]. Soil organic carbon was determined using the dichromate method [26]. Total nitrogen was determined using the semi-micro Kjeldahl method, modified according to Bremner [27]. Hydrolytic acidity was determined with Ca-acetate using the Kappen method [27]. The sum of adsorbed base cations was determined using the Kappen method, whereas base saturation (BS) and total cation exchange capacity (CEC) were computed [27]. The forms of easily available P_2O_5 and K_2O were determined following the Al method, and the available aluminum was determined according to the method of Sokolov [27].

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The soil does not contain gravel and is characterized by silt loam texture in the topsoil, and clay loam texture from 20–40 cm depth (Table 2). The clay content increases with depth in the soil profile, and the soil texture is clayey, with 46.1% clay content at 40–60 cm depth. Pre-experimental soil chemical characteristics are presented in Table 3. Soil at two depths had an acid reaction over 5.5 and lower than 6 in water solution, which is not a quite good medium for maize growth.

Table 2. Particle size distribution.

Depth (cm)	Particle size distribution (%, mm)					Soil texture
	0.25–2	0.05–0.25	0.05–2	0.002–0.05	<0.002	
0–20	0.8	25.0	25.8	56.3	17.9	Silt loam
20–40	0.9	21.2	22.1	44.1	33.8	Clay loam
40–70	0.3	17.3	17.6	36.3	46.1	Clay

Base saturation was between 56.9 and 65.7%, indicating the need to increase the pH for good maize production. The soil was poor in humus but had moderate levels of available phosphorus and potassium due to previous agricultural activities. Additionally, available aluminum was 5.3 and 9.2 mg · 100 g^{-1} in two depths, indicating potential toxicity problems with a decrease in soil pH.

Table 3. Soil chemical characteristics before the experiment.

Depth	SOM	pH		T–S	S	CEC	BS	N	P_2O_5	K_2O	Al
cm	%	H_2O	KCl	cmol kg^{-1}			%	%	mg · 100 g^{-1}		
0–30	1.86	5.60	4.10	10.6	14.0	24.6	56.9	0.120	9.0	15.2	5.3
30–60	0.72	5.63	4.02	8.5	16.2	24.7	65.8	0.066	8.1	16.4	9.2

SOM – Soil Organic Matter; S – Sum of Exchangeable Cations; T – Total cation exchange capacity, BS – Base Saturation; N – Total Nitrogen; P_2O_5 – available Phosphorus; K_2O – Available Potassium; Al – Available Aluminum.

2.3. Cultural Practices and Treatment Details

The experiment was carried out in the village of Ratina, at an elevation of 236 m above sea level. It was set up in a randomized block design with three replications. The size of the elementary plot was 35 m^2. The experiment included the following treatments: a) control treatment (unfertilized); b) fertilizer treatment: 155 kg·ha^{-1} of nitrogen, 80 kg·ha^{-1} of phosphorus, and 80 kg·ha^{-1} of potassium; and c) Liming with fertilization – 1000 kg·ha^{-1} of lime material with the same amount of fertilizer as in the second treatment. Liming material Terra Calco 95 is granulated, contains 77% CaO, and was produced in Jelen Dol, 55 km from Kraljevo. Lime material was added into the soil in the autumn together with the entire amount of phosphorus, and potassium, 80 kg·ha^{-1}, and deeply plowed. Pre-sowing soil preparation was carried out immediately before sowing, and an additional 75 kg N·ha^{-1} was applied. Manual sowing took place on April 17, 2020, and April 14, 2021. The spacing density was 5.71 plant/m^2, 70 × 25 cm. Maize hybrid ZP 606 was cultivated in both years. It is a mid-late hybrid from the Maize Research Institute in Zemun Polje, Serbia, belonging to the FAO group 600. Pests were controlled by integrated pest management practices that were standardized in the region. Additional agricultural practices during the vegetative period were thinning at the two-leaf stage to adjust the plant population to the desired levels, correction with herbicides at the 6-leaf stage, and two inter-row cultivations at the 8- and 12-leaf stages. Harvesting was done manually on October 31, 2020, and November 11, 2021. The total cob yield from each plot was measured, and after crowning, the harvest index was calculated. The total yield was recalculated to 14% moisture.

2.4. Statistical Analysis

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The maize grain yield obtained in the two seasons was statistically analyzed by analysis of variance (ANOVA) for a completely randomized design with three replications. The means were compared using Fisher's least significant difference (LSD) test at a 5% significance level. The analysis was conducted using the SPSS 20 statistical package.

3. Results

3.1. Effect of fertilizers and liming on soil characteristics

A short-term effect of the application of compound mineral fertilizers on soil chemical characteristics is presented in Table 4. Two-year application of fertilizers caused a small negligible increase in base saturation at both depths (around 3% of absolute increase). There was a small decrease in the content of available potassium and total nitrogen, and phosphorus at the second depth.

Soil chemical reaction in KCl decreased at both investigated depths, whereas soil reaction in water decreased at the depth of 30–60 cm for almost 0.2 pH units. The content of available aluminum increased for 8.0% at the first depth, and decreased for 9.0% at the second investigated depth. The amounts of fertilizers added did not change the amounts of available nutrients in the soil drastically, and that the doses were quite accurately determined. The content of humus decreased for 14.0% in the 0–30 cm depth, whereas the change in the second depth is less than 3%. Total nitrogen was also found to be decreased for around 12% at both investigated depths.

Mutual effect of liming and fertilizers on soil characteristics (Table 5) are more positive compared with previously presented fertilized treatment. The expected postitive effect of lime is evident on soil chemical reaction, base saturation, aluminum content at both depths, and available phosphorus. Soil reaction in both, water and KCl, are increased for 12.3 and 17.1%, and 9.8 and 16.9%, for the first and second depth, in water and KCl, respectively.

Table 4. Chemical characteristics of Pseudogley soil two years after the application of mineral fertilizers.

Depth	SOM	pH		T–S	S	CEC	BS	N	P_2O_5	K_2O	Al
cm	%	H_2O	KCl	cmol · kg^{-1}			%	%	mg · 100 g^{-1}		
0–30	1.60	5.60	4.00	10.6	12.8	23.8	54.7	0.106	9.2	13.8	5.7
30–60	0.70	5.42	3.80	10.5	17.5	28.1	62.4	0.058	7.2	15.5	8.4

SOM – Soil Organic Matter; S – Sum of Exchangeable Cations; T – Total cation exchange capacity, BS – Base Saturation; N – Total Nitrogen; P_2O_5 – available Phosphorus; K_2O – Available Potassium; Al – Available Aluminum.

The relative increase in base saturation is higher at the first depth, for more than 20%, from 56.9 to 69.3% in absolute values, but is also evident at the second depth, with 9.0% of relative increase. The highest relative change is observed in available aluminum content. It decreased from 2.3 to 5.4 times at the first and second depth, respectively.

Table 5. Chemical characteristics of Pseudogley soil two years after the application of lime and mineral fertilizers.

Depth	SOM	pH		T–S	S	CEC	BS	N	P_2O_5	K_2O	Al
cm	%	H_2O	KCl	cmol · kg^{-1}			%	%	mg · 100 g^{-1}		
0–30	1.47	6.29	4.50	7.1	16.1	23.2	69.3	0.100	18.3	21.2	2.3
30–60	0.66	6.59	4.70	7.4	18.7	26.1	71.7	0.065	15.5	17.5	1.7

SOM – Soil Organic Matter; S – Sum of Exchangeable Cations; T – Total cation exchange capacity, BS – Base Saturation; N – Total Nitrogen; P_2O_5 – available Phosphorus; K_2O – Available Potassium; Al – Available Aluminum.

The content of available phosphorus is increased after two years of lime and fertilizers application for 2.0 and 1.9 times at the first and second depth. The changes in the humus content were higher compared with only fertilized treatment. Namely, it is decreased for 21 and 8.3% at the first and second depth, respectively. Similarly to the content of humus, total nitrogen content is decreased for 16.7% at the first depth, and only 1.5%, at the 30–60 cm depth.

3.2. Effect of fertilization and liming on maize yield

The maize grain yield in the two seasons was affected by the treatment. In both years the lowest yield was recorded on the control treatment. The average yield was 2780 kg·ha^{-1} in 2020, and 1860 kg·ha^{-1} in 2021. The applied mineral fertilizers significantly increased the yield compared with the control to 9723.3 kg·ha^{-1} in 2020 and 9663 kg·ha^{-1} in 2021. The yield was the highest when mineral fertilizers were applied together with lime, 10170 and 10616 kg·ha^{-1}, in 2020, and 2021, but there were no statistically significant differences among fertilized treatments (Figure 1). The yield in limed treatment in 2021 was higher for 9.0% compared with fertilized treatment, whereas the change of 4.4% was found in 2020.

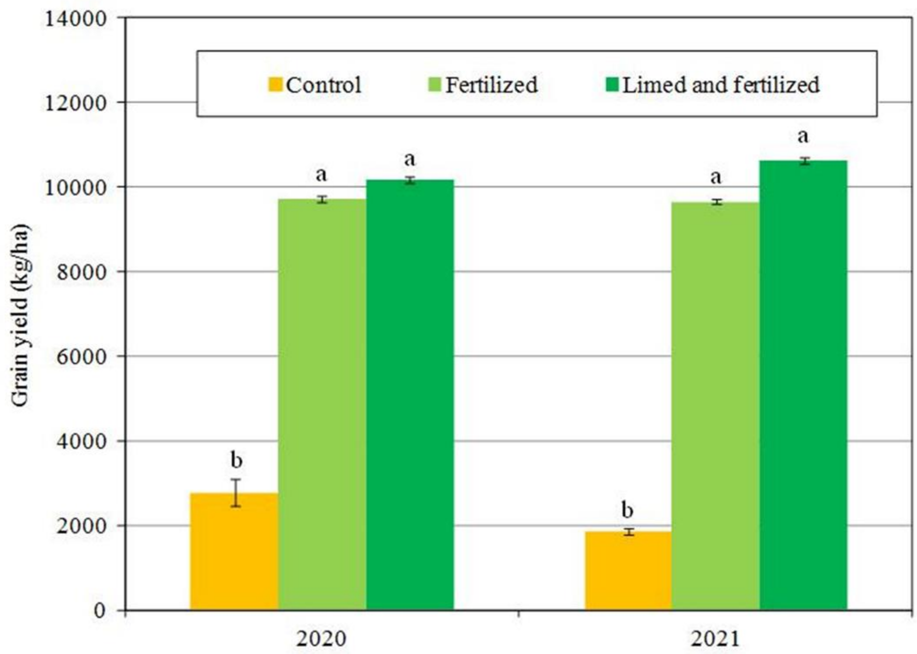

Figure 1. Grain yield of maize (14% moisture) per season and treatment; different lowercase letters indicate significant differences between treatments at $P < 0.05$.

4. Discussion

4.1. Effect of liming on soil characteristics

Similarly to the present study, the application of 1 t·ha^{-1} of lime significantly increased pH in Mecha district of Ethiopia [28] from 4.85 to 5.52, for 0.67 pH units, whereas the application of 3.5 t ·ha^{-1} increased pH to 6.21. Adane [28] reported that in Southern Ethiopia soil pH enhanced from 5.03 to 6.72 by applying 3.75 t ha^{-1} of lime, and that soil pH enhanced from 5.03 to 5.64, for 0.61 pH unit, after application of 1.25 t ha^{-1} of lime. In the present study, the addition of lime improved the main soil chemical properties, with evident benefits up to 0.60 m depth. The study of the effects of lime incorporation into the 0–40 cm depth of highly weathered tropical soils increased soil pH in water, and base saturation values in both 0–20 and 20–40 cm layers, in Minas Gerais state in southeastern Brazil [30]. Although lime has low solubility and mobility in soil, the results of the present study

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showed a rapid reaction of liming over a relative short period as in Tiritan et al. [31]. The application of 1 t·ha^{-1} of lime significantly increased base saturation in the study of Alemu et al. [28] from 69.8 to 72.4%, whereas after the application of 3.5 t·ha^{-1} increased base saturation to 75.6%. The effect of lime on base saturation on Pseudogley Soils in the present study resulted in higher increase; 12.2 and 5.9% of absolute increase in 0–30 and 30–60 cm depths, whereas this increase in base saturation with the application of 1.5 t·ha^{-1} of lime in the study of De Moraes et al. [30] is higher compared with the present study. In temperate conditions of Balkan Peninsula, Kovačević and Rastija [32] reported increase of pH in H_2O for 1.16 units (4.50 to 5.68) with the addition of 5 t·ha^{-1} of dolomite. However, these higher doses were added for higher pH increase, in order to increase the amount of available phosphorus in soil. The effect of liming and fertilization on available phosphorus reported in the present study is almost twice bigger in the 0–30 cm depth compared with the pre-experimental analysis, which is the similar trend to the results reported by Alemu et al. [28], for the same dose of lime applied. Total cation exchange capacity did not change in the present study with the addition of lime, which was already reported oppositely [28,29]. The application of 1 t·ha^{-1} of lime decreased organic carbon content [28] from 2.19 to 1.89% (more than 15%) in Ethiopia, whereas in the present study the decrease is even higher, 21% at the 0–30 cm depth. Contrary to previous findings, Crusciol et al. [33] found the significant increase in soil organic matter (SOM) after application of lime and N fertilization. The enhanced effect of liming on SOM content was found up to a depth of 0.10 m, whereas at the highest lime rate, the positive effect of N fertilization on SOM content propagated up to a depth of 0.4 m. There was no statistically significant changes in SOM content with the addition of 5, 10 and 15 t·ha^{-1} of dolomite in Slavonia region of Croatia [32]. The impacts of liming on soil carbon storage are variable and strongly relate to soil type, land use, climate and multiple management factors [15]. The higher decrease in SOM content in temperate conditions of Serbia may be attributed to very low pre-experimental SOM content, to moist conditions during the investigated seasons, and increased microbiological activity at higher pH values. Also, in the experiments in Ethiopia, Brasil and Croatia initial soil organic carbon contents were higher. The application of 1 t·ha^{-1} of lime decreased total nitrogen content from 0.17 to 0.139% in Alemu et al. [28], which is around 20% of decrease as in the present study. Alvarez et al. [34] reported a fundamental role of long-term N application in increasing SOM levels, but these effects are due to the increase in residues returned to the soil. The soil had high content of available aluminum before the experiment, which was very close to threshold value of 10 mg · 100 g^{-1}. Liming reduced available aluminum in the soil but on only fertilized treatment, its content remained quite consistent and still presents a potential toxicity problem.

4.2. Effect of fertilization and liming on maize grain yield

In the present study, total grain yield significantly increased with liming. The applied lime didn't show any significant effect on maize grain yield compared with the fertilized treatment, but the application of lime still increased the yield compared with that treatment. Contrary to our findings, the effect of different doses of phosphorus fertilizers (750, 1250, and 1750 kg·ha^{-1}) applied on strongly acid soils in Northern Bosnia did not have significant effects on maize grain yield [35], above all, because of the lack of available phosphorus for plants. The maximum increase in grain yield in their study was only between 0.38–1.72 t·ha^{-1}. This is also attributed to the lower initial pH value of the soil in their study. Moreover, ameliorative P fertilization has been found as useful for yield increases but these effects are mainly lower compared to fertilization and liming [36] mutual impact. Positive effects of liming and P fertilization on yields of maize in the temperate region of Balkan were found also by the earlier studies [32,37]. All these results indicate the necessity for liming application and phosphorus mobilization in the soils, and strive for the improved and better organized liming management in the region. In fact, liming and increased P fertilization are common recommendations for improvement of Pseudogley Soils over Balkan.

4.3. Liming environmental footprint

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According to several authors which conducted maize liming experiments recently [30,33,38], the greatest crop yield increases were found with higher rates of lime. Hence, these positive results should also consider for the potential emission of GHG after liming application. The results obtained in this study are potentially environmentally friendly as the good effects on grain yield of maize were obtained with small doses of lime. Theoretically, the applied doses of lime released less CO_2 into atmosphere. Agriculture accounts for roughly 12% of GHG emissions per year. It is at the same time highly vulnerable sector and also the one having considerable mitigation potential. CO_2 emissions after liming are potentially smaller, if smaller doses are applied. These emissions can be compensated if liming leads to more efficient use of fertilizers and improves the yields in the most efficient manner. Therefore, the environmental benefits of liming can add justification to public investments in soil liming besides other motivations such as safeguarding long-term soil fertility and improving farmer's livelihoods [21].

4.4. Liming application in Western Serbia: problems and perspectives

Liming is a common management practice around the world, but with lot of uncertainty about the economic feasibility. The analysis carried out in Western Kenya including costs of labor and associated profits across a period of five years were only positive when liming was combined with fertilizer application [21]. Similar results are obtained in Brazil [39]. The highest economic benefits of lime application are achieved with the higher lime treatments, but lime should be considered a capital investment and economic evaluation should be undertaken over a long period. The analysis depends on a given crop rotation and cannot observe maize separately, and should also take into account long-term effects. Furthermore, the focus on lime rate is important from economical and environmental aspects but also the frequency of lime application. Economic response to liming varies among the soils [15] which make this analysis more complex. The other factors affecting liming feasibility are quality of liming material, supply of nitrogen, and crop price risk and lime input costs. In Kenya liming as long-term economic strategy can be problematic for farmers who lack investment capital and who may have short-term decision time frames [21]. This also implies to most smallholder farmers in Serbia. The amounts of required lime, whether they are smaller or higher, have high transportation requirements. This might be one of the reasons for the low application of liming in Serbia. This problem can be solved with the utilization of railway for the transportation of liming material in Western Serbia, as there are quite good logistics for that. In this manner, the cost of transportation can be diminished for farmers, and they will be enabled to place larger quantities of lime on their farms and apply the lime with the appropriate liming rates and frequencies. The Ministry of Agriculture had already subsidized liming material a decade ago, but the practical professional application lacked. Since there are still needs for liming, the new potential subsidy from the state can reduced cost of liming material, and with further consolidation of small agri-holdings, liming might become a regular agricultural practice on acid soils. Luvisols and Pseudogleys are acid soils in Serbia used in agricultural production. Luvisols are located in hilly regions and used for intensive raspberry production, whereas Pseudogley Soils are found on lower terrains and have some other associated problems. The effect of liming on them is affected by soil water regime, depth of impermeable layer, and its compactness, in addition to poor fertility and potential toxicity problems. In order to increase the effect of liming and fertilization on Pseudogley Soils it is required to improve water-air regime of these soils. The most adequate and not very often used measures in Serbia are deep tillage, subsoiling and pipe drainage. These measures are costly but provide many benefits to soil and production on a long-run. By this manner, the effect of lime will be multiplied. Nevertheless, the potential increase in pH after liming enables the introduction of some new crops in rotation. In Čačansko-Kraljevački region, there is a lack of good quality animal feed, and therefore, alfalfa as an important forage crop can be included in crop rotation. Liming management appears to be very complex and requires good organization. Application of lime with other complementary agricultural practices offers substantial yield improvements [40], but unfortunately liming is a measure which is very modestly applied in Serbia. In the current context, uptake of liming in Serbia seems unlikely to happen without external initiatives, regional programmes, facilitation and incentives.

4.5. Liming sustainability

The obtained results of yield in two fertilized treatments are satisfactory for the conditions of Western Serbia. There is a small no significant difference in yield between limed and only fertilized treatment. However, the positive effect of lime is notable on soil characteristics. It is related to increase in pH, base saturation and available phosphorus, and decrease in available aluminum. In only fertilized treatment, there is a very small decrease in pH and base saturation, whereas the amount of aluminum remained consistent. Although small in this experiment, this negative trend in soil characteristics on only fertilized treatment might become more intensive in the future, if fertilizers are applied without lime, and provoke stronger deterioration of soil properties and possible increase in aluminum and its toxicity. Therefore, from the point of view of long-term sustainability of maize production, liming appears to be not additional but necessary measure.

The sustainability of liming application in Western Serbia also requires economic analysis which was not yet conducted. The audience usually requires straightforward economic benefits of liming. However, this uncertainty is likely to be positive rather than negative in conditions when liming is accompanied with regular management practices, such as fertilizer application, manuring, deep tillage and irrigation. The best way to solve this uncertainty is to develop a framework for liming application in order to improve food security in the Čačansko-Krajevački region. It should particularly refer to Pseudogley Soils due to its above-mentioned constraints. From the point of view of long-term sustainability of maize production on acid soils liming appears to be a measure which is underrated. This framework should include all the factors referring to lime management and include monitoring of the effects of liming on soil health and crop production, whilst computing the environmental footprint of liming. In the current context, uptake of liming in Serbia seems unlikely to happen without external initiatives. Therefore, the development of this framework can be triggered after local incentives and include actors from farm management to decision making level. It should be focused on developing management protocols which will promote liming as sustainable soil management practice.

5. Conclusions

The positive effect of liming and fertilization is observed after two-years of the experiment on Maize grown on Pseudogley Soils. The significant yield improvements are observed in both fertilized treatments compared with the control. The differences in yield between the fertilized treatments with and without liming were not significant although the higher yields for 4.4–9.0% were obtained in limed treatment. However, the applied 1 t of lime per hectare affected soil characteristics. Soil reaction in water and KCl was reduced, base saturation increased, and liming increased the availability of phosphorus, whereas the content of available aluminum decreased. The applied mineral fertilizers without liming affected soil chemical characteristics in a different manner. There is a small decrease in pH and base saturation, whereas the amount of aluminum remained consistent. Therefore, the additional application of fertilizers without lime on a long-run can foster negative trend in soil characteristics and provoke stronger deterioration of soil properties and possible increase in aluminum and its toxicity. This could potentially affect food security. This practically means that liming is sustainability measure in crop production and it should be conducted on a regular basis. However, in Serbia, the liming application is still very modest because of unknown economic feasibility and bad organization, and it seems that in the current context uptake of liming in Serbia seems unlikely to happen without governmental/regional support via programmes, facilitation and incentives. Long-term sustainability of maize production on acid soils is at the threat whereas the liming appears to be underrated. Therefore, there is a need to develop liming application framework to solve these problems. This framework should include all the actors and factors referring to liming management and be focused on developing protocols promoting liming as sustainable management practice which at the same time enhance crop production, improve soil health and save the environment.

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