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Effect of Lime, Mineral Fertilizer and Manure on Soil Characteristics and Yield of Four Maize Hybrids

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Abstract: Pseudogley soils in Serbia are characterized by poor chemical and physical properties that limit maize yields. Nevertheless, they are still used on large areas due to their favorable topographic position and lack of better-quality soils. It is common practice to regularly apply mineral fertilizers to these soils, but this does not increase maize yields to an economically sufficient level, although the doses are increased. At the same time, the inappropriate application of mineral fertilizers deteriorates soil chemical properties. Lime is only moderately used in Serbia despite its known benefits, whereas manure is not satisfactorily used. Therefore, a two-factorial experiment was set up as a randomized block design with three replications and conducted near Kraljevo, Serbia, to investigate the effect of mineral fertilizers, manure and lime on maize growth. The experiment included three fertilization regimes: F—application of common fertilizer doses, LF—application of the same fertilizer doses with 3 t·ha^{-1} of lime, and LMF—application of the same fertilizer doses with lime and 30 t·ha^{-1} of manure. The response of four maize hybrids to different fertilization practices was investigated. The soil was acid, poor in humus, and contained an increased content of mobile aluminum. There was a significant increase in the 3-year average yield of all hybrids in LMF- and LF-treatments compared with F-treatment, 30.7 and 25.6%, respectively. The increase in yield was accompanied by an improvement in soil chemical properties after three years, i.e., increased soil reaction in LF- and LMF-treatments, increased content of available phosphorus, an increase in base saturation by 61 and 75%, and aluminum immobilization by 2.55 and 4.19 fold, respectively, compared to initial conditions. The hybrid NS 640 demonstrated the highest yield when only mineral fertilizers were used, which indicated its tolerance to the unfavorable physical and chemical soil properties and suggested that it can be recommended for growing on pseudogleys without applying amelioration practices. The hybrids NS 6030 and ZP 606 achieved statistically significantly higher yields than the other hybrids when lime and manure were applied, which indicates that adequate fertilization coupled with soil improvement practices should be used in order to achieve satisfactory yields. The obtained results showed that liming can be considered as a longer-term sustainability practice in maize production in Serbia on pseudogley soils, and that there is an array of maize hybrids which can be grown depending on management strategies applied.

Keywords: acid soil; base saturation; chemical amelioration; food security; maize; mobile aluminum; pseudogley soil

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1. Introduction

Maize occupies the largest area of all field crops grown in Serbia; it is sown on approximately 1,200,000 ha of land, with an annual production of 4–6 million tons. Although the hybrids of a new generation with high genetic fertility potential have been introduced into production, the five-year (2019–2023) average maize yield in Serbia, 6.75 t·ha^{-1}, is lower than those achieved in the USA and France, 10.88 and 7.37 t·ha^{-1}, and higher than reported in Brazil and Mexico, 5.40 and 3.91 t·ha^{-1} (https://ipad.fas.usda.gov/, accessed on 19 February 2025). One of the reasons for the lower yields of maize is its wide cultivation on soils with variable productivity in terms of their agro-potential. Some of these soils, such as pseudogleys, are characterized by poor water–air and nutrient regimes, acidic reaction, low natural fertility and potential aluminum toxicity. The total area of pseudogleys in Serbia is not less than 500,000 ha [1], and approximately three-quarters of it is located in Western Serbia. Pseudogley soils in Western Serbia are mainly related to flat and undulating, slightly sloping terrain. In this area, there are a lot of small dairy cow farms with a great need for silage and maize grain of good quality, which indicates the importance of pseudogley soils. Dugalić [2] investigated the properties of forest, meadow and field pseudogley varieties of the Čačak–Kraljevo basin and found that their pH in water ranged from 5.0 to 5.5 in the Ah horizon, and pH in KCl from 3.7 to 4.9, and that a portion of exchangeable acidity is related to the presence of aluminum ions, which in large quantities exhibit toxicity.

The causes of pseudogley acidity in Serbia are in the first instance natural, but in the second instance, they are anthropogenic and are caused primarily by agricultural activities through the long-term use of high doses of nitrogen fertilizers, without the use of organic fertilizers [3–5]. On acidic soils, the availability of nutrients, especially phosphorus, is low [6] because the sorption capacity of phosphorus increases with increasing acidity; therefore, a frequent deficiency of readily available phosphorus in these soils, despite the regular application of mineral fertilizers, is the cause of poor root system development in maize and its low grain and silage yields. Soil acidity also causes a decrease in the content of base cations required for plant growth, and can lead to phytotoxic concentrations of aluminum [7]. As soil acidity increases, pH decreases, the concentrations of Al^{3+} and H^{+} cations in the soil increase, while basic cations such as Ca^{2+}, Mg^{2+}, and K^{+} are increasingly leached or absorbed [6]. A high aluminum content in acidic soils affects plants, soil microbes, and the environment [8] and is particularly toxic in soils with low concentrations of magnesium and calcium, and toxicity increases even more in soils where the chemical reaction is below pH = 4.5 [9–11]. In contrast, aluminum precipitated or chelated with organic compounds is not toxic to plants [12,13], and that is why it is very important to introduce organic fertilizers in acidic soils, as well as to reclaim the soils by liming. The application of livestock manure increases soil pH [14–16], and aluminum tends to bind to organic matter forming strong insoluble complexes [17,18], which thus prevent its harmful effects. In Serbia, the content of 6–10 mg·100 g^{-1} of soil of easily mobile Al^{3+} ions is considered to have an unfavorable effect on the growth of most field crops.

The soil reaction in water between pH 6 and 7 satisfies the requirements of maize, whereas more acid soils are generally improved by the application of lime. Liming is one of the most common practices to ameliorate acid soil, and it has many well understood benefits [19], but it is still only modestly used in Serbia as there is not a complete recommendation protocol about the amount of liming material required to neutralize acidity, and the amount of manure and lime in combination with mineral fertilizers to improve acid soil characteristics and provide a stable and good-quality yield of maize. Liming alone, as well as when applied jointly with mineral and organic fertilizers, has enabled effective regulation of the physical and chemical properties of leached chernozems in the forest-steppe zone of the South Urals, thus contributing to the improvement of soil fertility [20]. The

processes of soil acidification and degradation of the chemical properties of pseudogleys are still on-going and, hence, leading to the further deterioration of the soil structure. In addition, maize producers have realized that the new hybrids do not express their genetic potential despite the application of increased doses of mineral fertilizers For both these reasons it is important to investigate how calcareous material reduces acidity and how, in combination with organic and mineral fertilizers, a stable maize yield can be achieved and the productive capacity of these soils improved.

In addition to improving soil fertility by introducing lime, manure and different doses of mineral fertilizers, some acid soil researchers have suggested testing different genotypes of cultivated plants for their tolerance to poor soil conditions, in order to single out tolerant genotypes, primarily to increased concentrations of Al ions. In contrast to the world frameworks [21–23], in Serbia there is a lack of data on the tolerance of maize hybrids to increased mobile aluminum levels, with producers firmly believing that older generation hybrids tolerate the poor characteristics of pseudogleys better than new ones.

The aim of this work is to examine the effect of mineral and organic fertilizers, and the introduction of lime, on the production of four maize hybrids on low fertility soils, as well as to determine to what extent the applied practices improve the agrochemical properties of pseudogley soils.

2. Materials and Methods

2.1. Study Area

2.1.1. Climate

The study area is characterized by a temperate climate. The monthly long-term average air temperature in the period 1990–2019 was 11.9 °C, whereas the highest temperature was in July, 22.4 °C. The average air temperature in the same period for the vegetative season of maize (April–September) was 18.5 °C. The annual long-term sum of precipitation was 752.1 mm, whereas the sum of precipitation for the vegetative period was 434 mm. The climate is characterized by mild winter periods and moderately dry summers, and high rainfall variability during the vegetative season. The highest amount of rainfall was recorded in the period May–June, and the driest period was between July and September.

2.1.2. Soil

The soils of the broad area are characterized by the waterlogging at the depth of occurrence of the impermeable illuvial horizon. In the majority of cases, mottling and albic properties are found at some depth beneath the surface (mostly at 30–60 cm). The reason for water stagnation is the presence of a very compact soil horizon rich in clay. Therefore, these soils have a small physiological thickness, although the entire thickness of the soil profile is higher than 1 m, as they are formed on diluvial terraces. This smaller soil thickness is a constraint on better root growth and development. Additionally, these soils have unfavorable porosity in the illuvial horizon and a very low presence of macro-pores. Also, the grade of soil structure development is weak in natural pseudogleys, but it is worse in those used in agricultural production. Their overall chemical characteristics are not favorable [2], i.e., a low amount of soil organic matter, soil pH in water often less than 5.5 in Ah horizons and lower in the eluvial horizon, thus causing the presence of available aluminum and certain toxicity problems. Nevertheless, favorable landscape position and good topography makes these soils somewhat favorable for field crops. Farmers know the weaknesses of these soils, including an unpredictable water–air regime and potential soil acidity problems, which are solved to a moderate degree by liming or other reclamation practices.

2.2. Experimental Details

Three-year field research was conducted in the period 2021–2023 near Kraljevo, Central-Western Serbia. A two-factorial experiment set up as a randomized block design with three replications was conducted near the village of Ratina (43°42′03″ N, 20°45′02″ E), few kilometers from the city of Kraljevo. Plot size was 105 m^2 (10.5 m × 10 m). The experiment included three regimes of fertilization management (fertilization treatment) and four hybrids of maize. Fertilization regimes were: F—application of common fertilization doses: 155 kg·ha^{-1} of nitrogen, 80 kg·ha^{-1} of P_2O_5, and 80 kg·ha^{-1} of K_2O; LF—application of the same fertilization doses with 3 t·ha^{-1} of lime; and LMF—application of the same fertilization doses with liming and 30 t·ha^{-1} of manure. The four maize hybrids used for the experiment were produced at the Maize Research institute in Zemun Polje (ZP 606, ZP 666) and Institute for Field Crops and Vegetables in Novi Sad (NS 640 and NS 6030), Serbia. All investigated maize hybrids are mid-late hybrids with potential dry grain yield higher than 15 t·ha^{-1}. The crop grown before maize was winter wheat. The applied aged manure was produced on a small family dairy farm where wheat straw was used as bedding. Terra calco 95 granulated lime material (77% CaO or 55% of Ca) is produced in Jelen Do near Požega, Western Serbia. According to the hydrolytic acidity calculation method, the required amount of lime for soil amelioration should be higher, but we shared an opinion that multiple applications of moderate amounts of the soil amendment are more appropriate from the point of view of soil restoration and nutrient regime than a single addition of high lime doses, as it was presented in [19]. Large amounts of liming material added at once cause the immobilization of the available forms of nutrients, especially in the emergence stage of maize. This is the case particularly if organic fertilizers are not applied. The total amount of lime, manure, and 80 kg·ha^{-1} of phosphorus, potassium and nitrogen was ploughed during autumn deep ploughing. Fertilization was conducted with 500 kg·ha^{-1} of NPK (16:16:16) (HIP Azotara, Pančevo, Serbia). Immediately before sowing, additional 280 kg·ha^{-1} of calcium-ammonium nitrate (75 kg N·ha^{-1}, 14 kg Ca·ha^{-1}) (Nitrogénművek Zrt., Pétfürdő, Hungary) was applied.

Manual sowing took place on 14 April 2021, 17 April 2021, and 9 April 2023. Spacing was 70 × 25 cm, approximately 57,000 plants per hectare. After sowing, and before emergence, weeds were controlled (Nitrogénművek Zrt., Pétfürdő, Hungary) every year by pest management practices that are standardized in the region. Thinning was carried out every year at the 3–4-leaf stage to adjust the plant population, whereas correction with herbicides was conducted at the 6-leaf stage. Inter-row cultivations were conducted once in 2021 at the eight-leaf stage, and in 2022 and 2023 at the eight- and twelve-leaf stage, in order to break out the crust and provide the necessary aeration. Harvesting was performed manually on 2 October 2021, 3 October 2022, and 6 October 2023. The total yield was corrected to 14% moisture content.

2.3. Soil Sampling and Laboratory Analysis

A soil profile was excavated before the experimental setup in order to describe the soil and determine the most important physical and chemical properties. The soil was classified as a moderately deep pseudogley. Soil samples were collected from designated horizons at 0–30 cm, 30–45 and >45 cm soil depths. Soil samples for soil texture analysis were collected from the open soil profile. Soil chemical characteristics were determined from composite soil samples collected from 0–30 and 30–45 cm depths with auger, before planting and after harvesting in 2023, from five points using the crisscross sampling technique, and from each experimental plot.

The combination of sieving and pipette method was used for the determination of particle size distribution [24]. Soil textural class was determined according to the USDA soil

textural triangle. The potentiometric method (Mettler–Toledo, Greinfensee, Switzerland) was used to measure soil pH values in water (1:2.5) and 1 M KCl (1:2.5) suspensions [24]. The dichromate method was used to determine soil organic matter (SOM) [24]. Total nitrogen was determined using the semi-micro Kjeldahl method, modified according to Bremner [25]. The Kappen method [25] was used to determine hydrolytic acidity and sum of adsorbed base cations. Base saturation (BS) and total cation exchange capacity (CEC) were computed [25]. Available P_2O_5 and K_2O were determined following the Al method of extraction with lactic acid [26] (Lach-Ner, s.r.o., Neratovice, Czech Republic). Available aluminum was determined according to the method of Sokolov [25].

2.4. Statistical Analysis

The maize grain yield obtained in the two seasons was statistically analyzed by the analysis of variance (ANOVA) for a two-factorial (fertilization treatment × hybrid) completely randomized block design with three replications, whereas soil chemical characteristics were also analyzed by ANOVA for a two-factorial (fertilization treatment × soil depth) completely randomized block design. The means were compared using Fischer's protected least significant difference (LSD) test for comparison among soil depths, whereas the LSD test was used to compare the means of grain yield, and soil characteristics among the fertilization treatments, at the 1 and 5% significance level, respectively. The analysis was conducted using the SPSS 20.0 statistical package.

3. Results

3.1. Weather Conditions

Monthly and annual air temperatures were higher in all three experimental years than the long-term average. Average air temperatures in the vegetative periods during the experiment (Figure 1) were also higher. The warmest season was 2022, with average air temperature during the vegetative period of 19.3 °C, followed by 2021 and 2023, with 18.9 °C and 18.7 °C, respectively. The air temperatures recorded might be considered optimal for maize production. The sum of precipitation during the vegetative period was almost 150 mm lower in the 2021 season compared with the long-term averages (1990–2019). In 2022 and 2023, the sum of precipitation was 30 and 70 mm higher, respectively, but was characterized by monthly variability. On the one hand, the 2021 season can be considered as moderately dry, whereas on the other, the 2023 season had no severe dry spells. A very low amount of rainfall was recorded in May and June 2021, 26.3 mm and 56.9 mm, respectively, whereas the higher amount of rainfall in July was not sufficient to compensate for higher yield losses, but it nevertheless stopped enormous drought. The year 2022 was characterized by a dry period at the beginning of the growing season, but soil moisture was partially compensated in the very wet month of June (127.5 mm), whereas another dry spell occurred in July, but moisture was again replenished in August, 124.9 mm. In 2023, the highest amount of precipitation was recorded in June, 132.5 mm, May, 125.0 mm, and April, 75.8 mm. There was slightly less precipitation in August and September (56.9 and 42.9 mm, respectively), but thanks to the favorable distribution of precipitation in May and June, and partly in the first and second ten-day periods of July, the year 2023 was meteorologically favorable. The monthly averages of climate characteristics during the experimental period are shown in Figure 1.

3.2. Pre-Experimental Soil Characteristics

The investigated soil is of the pseudogley soil type according to the national soil classification system [27]. The soil profile has an Ah–Eg–Btg soil horizon sequence, which indicates water stagnation below the humus-accumulative layer. The Ah horizon is light

grey, and has a weak grade of soil structure development, and a thickness of 30 cm, which might correspond to soil tillage depth. The subsurface Eg horizon is 15 cm thick (from 30 to 45 cm depth), even lighter in color than the overlying horizon, structureless and has stagnic properties, with orsteinic concretions. The Btg horizon is very dense and compact, weakly permeable, characterized by a higher clay content, light brown, and has a lower abundance of stagnic properties compared with the overlying horizon. The particle size distribution of the investigated soil is presented in Table 1. Silty clay loam soil texture is present in two upper layers, with a small amount of sand fraction (approximately 10%). A great textural differentiation is found at 45 cm depth, where more than 15% higher clay content was found compared with the two upper layers, 45.7%.

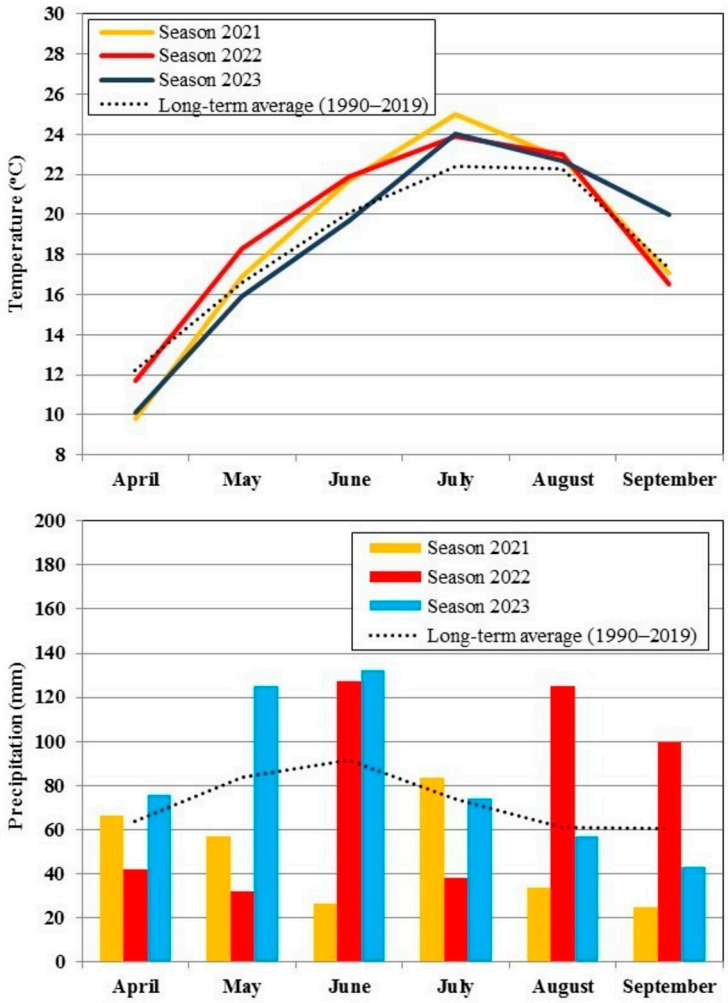


Figure 1. Monthly averages of air temperatures and precipitation during the three investigated seasons (2021–2023) and long-term average (1990–2019) (dotted line); data were obtained from the meteorological station in Kraljevo, approximately 2 km from the experimental field.

Table 1. Particle size distribution of the investigated pseudogley profile.

Depth (cm)	Particle Size Distribution (%, mm)					Soil Texture
	0.25–2	0.05–0.25	0.05–2	0.002–0.05	<0.002	
0–30	5.5	6.2	11.7	8.2	28.8	Silty clay loam
30–45	4.2	5.8	10.0	8.3	28.8	Silty clay loam
>45	1.0	4.4	5.4	7.0	45.7	Silty clay

The chemical properties of the pseudogley are quite unfavorable, as presented in Table 2. The content of humus at first 30 cm is only 2.24%, and in the subsoil, it drops sharply to 1.34%. A lower amount of humus in the humus-accumulative and subsurface horizons is a typical characteristic of pseudogleys in this part of Serbia. The soil reaction in water is acid, 5.04 and 4.98, at 0–30 and 30–45 cm depths, respectively. The sum of exchangeable bases (S) is almost equal at both investigated depths, whereas soil hydrolytic acidity (T–S) is higher in the topsoil, but base saturation is approximately 50% at both depths, indicating the necessity to improve the soil reaction.

Table 2. Soil chemical characteristics before the experiment.

Depth	SOM	pH		T–S	S	T	BS	N	P_2O_5	K_2O	Al
cm	%	H_2O	KCl	$cmol \cdot kg^{-1}$			%	%	$mg \cdot 100\ g^{-1}$		$cmol \cdot kg^{-1}$
0–30	2.24	5.04	4.13	10.7	10.9	21.6	50.2	0.12	9.0	15.2	1.15
30–45	1.34	4.98	4.02	8.8	8.1	16.9	48.0	0.07	8.1	16.4	1.02

SOM—soil organic matter; T–S—hydrolytic acidity; 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.

3.3. Effect of Fertilizers and Liming on Soil Characteristics

The results of ANOVA presented in Table 3 show statistically significant differences in the soil reaction in water depending on fertilization treatment, but without significant differences at two investigated depths. The soil reaction in water decreased non-significantly in F-treatment compared with the pre-experimental soil reaction (4.98 to 5.04, Table 2). The application of lime in the other two treatments increased pH in water by 1.25 and 1.54 pH units, and was significantly higher compared with F-treatment. The soil reaction in water was significantly higher in LMF-treatment than in LF-treatment without manure. The soil reaction in KCl was better affected by liming as there was no significant difference in two limed treatments, whereas they were both significantly higher than in F-treatment.

Table 3. Soil chemical characteristics three years after the application of fertilizer, lime and manure at different soil depths.

Soil Characteristic	pH		SOM	N	T–S	S	T	BS
	H_2O	KCl	%	%		$cmol \cdot kg^{-1}$		%
Treatments								
NPK	4.96 c	4.20 b	1.71 b	0.079 b	9.8 a	9.0 c	18.8 c	48.8 c
NPK + liming	6.21 b	5.59 a	1.50 c	0.081 b	5.3 b	19.3 b	24.6 b	78.5 b
NPK + liming + Manure	6.50 a	5.70 a	2.49 a	0.121 a	4.8 b	27.9 a	32.7 a	85.4 a
Soil depth (cm)								
0–30	5.86	5.16	2.47 a	0.121 a	6.4	17.8	24.12 b	70.0
30–45	5.90	5.16	1.32 b	0.066 b	6.9	19.8	26.58 a	71.8

SOM—soil organic matter; N—total nitrogen; T–S—hydrolytic acidity; S—sum of exchangeable cations; T—total cation exchange capacity; BS—base saturation. Different lowercase letters added to averages in columns indicate significant differences between treatments at $p < 0.05$.

ANOVA results indicate that there were statistically significant differences in SOM content between the applied fertilization treatments, as well as between the investigated depths. Lime in combination with mineral fertilizers affected SOM content. In the treatment with lime and fertilizers, SOM content (1.50%) was significantly lower than in F- and LMF-treatments. SOM content in LMF-treatment (2.49%) was significantly higher than in F-treatment (1.71%). Also, SOM content was significantly different at two investigated

depths, being higher in the topsoil. Total nitrogen content was significantly higher in LMF-treatment where 30 t·ha^{-1} of manure was applied than in the other treatments. Also, after three years of the experiment, nitrogen content was significantly higher in topsoil compared with subsoil. Liming applied with fertilizers significantly decreased hydrolytic acidity to 5.29 cmol·kg^{-1} of soil, whereas in LMF-treatment it decreased significantly to 4.81 cmol·kg^{-1} of soil. There were no significant differences between the two liming treatments in the way they affected hydrolytic acidity. The application of lime with fertilizers or lime with manure and fertilizers decreased soil acidity and accordingly increased base saturation. However, base saturation in LMF-treatment was significantly higher (85.4%) than in the other two treatments, whereas base saturation in LF-treatment (78.5%) was significantly higher than in the only fertilized treatment, which was dystric (48.8%). There were no significant differences in base saturation between the two investigated depths. Hence, liming, or liming and manure, increased base saturation by approximately 28–35% absolute value, thus affecting biochemical processes in the soil.

The highest phosphorus content after the three-year period was measured in LMF-treatment (16.6 mg·100 g^{-1}), and it was significantly higher than in F-treatment (6.6 mg·100 g^{-1}) (Table 4). LF-treatment had only 1 mg of P_2O_5 in soil less than LMF-treatment, and this difference was not significant, whereas it was significantly higher than P_2O_5 content in F-treatment. Also, there were statistically significant differences in the phosphorus content between the topsoil and the subsoil. The highest content of potassium was measured in LMF-treatment (20.8 mg·100 g^{-1}), which was significantly higher than in the treatment with only mineral fertilizers (17.7 mg·100 g^{-1}), but without significant differences compared with LF-treatment (20.5 mg·100 g^{-1}). There were no significant differences in potassium content between the two investigated depths. The smaller differences found in potassium content compared to phosphorus content are typical of Serbian soils, which are naturally moderately rich in potassium, and poor in phosphorus. The lowest content of available aluminum after the three-year period was found in LMF-treatment (0.22 cmol·kg^{-1}), and it was not significantly different compared with LF-treatment (0.36 cmol·kg^{-1}). Therefore, limed treatments had, respectively, 4.2- and 2.6-fold lower amounts of available aluminum than F-treatment, which was one of the goals of the liming operation. These values were significantly lower than the values of available aluminum (0.92 cmol·kg^{-1}) under F-treatment, which remained close to the threshold value of 1 cmol·kg $^{-1}$ [2]. The content of available aluminum did not vary significantly at two investigated depths.

Table 4. The content of available phosphorus, potassium and aluminum three years after the application of fertilizer, lime and manure at different soil depths.

Soil Characteristic	P_2O_5	K_2O	Al
	mg·100 g^{-1}	mg·100 g^{-1}	cmol·kg^{-1}
Treatments			
NPK	6.6 b	17.7 b	0.92 a
NPK + liming	15.6 a	20.5 ab	0.36 b
NPK + liming + manure	16.6 a	20.8 a	0.22 b
Soil depth (cm)			
0–30	12.4 a	17.9	0.66
30–45	10.2 b	18.3	0.59

P_2O_5—available phosphorus; K_2O—available potassium; Al—available aluminum. Different lowercase letters added to averages in columns indicate significant differences between treatments at $p < 0.05$.

3.4. Effect of Fertilization and Liming on Maize Yield

3.4.1. Maize Yield in 2021

In the first year of the research, 143.3 mm less precipitation was recorded during the growing season, compared to the long-term average. This amount of precipitation was the lowest in the three years of the research, and accordingly, the lowest average yield was achieved in 2021 (Table 5). The results indicate significant differences in maize grain yield between treatments, regardless of the hybrid, and no differences between individual hybrids on average for all fertilization treatments.

Table 5. Effect of fertilization treatment on the yield of different maize hybrids in the three investigated seasons (2021–2023).

Year	Treatment—T	Hybrid—H				Mean ± SEM
		NS 640	ZP 606	NS 6030	ZP 666	
2021	F	6601.0 cd	5283.0 e	6233.4 d	6249.3 d	6091.7 ± 180.4 B
	LF	6977.7 bc	7658.8 a	7495.6 ab	7367.6 ab	7374.9 ± 106.4 A
	LMF	7329.7 ab	7767.5 a	7588.8 a	7227.0 ab	7478.2 ± 91.5 A
	Mean ± SEM	6969.5 ± 142.2	6903.1 ± 410.7	7105.9 ± 254.8	6948.0 ± 193.5	6981.6 ± 129.8
	LSD	F 283.42 ns	H 327.3 ns	F × H 566.83 **		
2022	F	8612.7 e	7824.5 f	8066.8 f	8108.2 f	8153.0 ± 98.2 C
	LF	9348.5 d	9904.6 c	10,135.8 bc	9969.1 bc	9839.5 ± 119.5 B
	LMF	9830.7 c	10,943.5 a	11,056.0 a	10,391.9 b	10,555.5 ± 162.2 A
	Mean ± SEM	9263.9 ± 186.9 C	9557.5 ± 462.7 AB	9752.9 ± 454.3 A	9489.7 ± 358.3 BC	9516.0 ± 185.1
	LSD	F 226.57 **	H 261.54 **	F × H 453.01 **		
2023	F	8724.2 f	7779.5 gh	7679.9 h	8035.1 g	8054.7 ± 132.2 C
	LF	9855.1 e	11,221.5 bc	11,289.4 b	10,767.5 d	10,783.4 ± 176.1 B
	LMF	10,128.2 e	11,969.7 a	11,438.8 b	10,931.1 cd	11,117.0 ± 212.5 A
	Mean ± SEM	9569.1 ± 220.4 C	10,323.6 ± 646.4 A	10,136.0 ± 620.7 A	9911.3 ± 470.5 B	9985.00 ± 252.1
	LSD	F 163.67 **	H 188.98 **	F × H 327.31 **		

Seasonal means in columns (hybrid) and rows (fertilization treatment) in each year followed by the same capital letter are not significantly different at $p < 0.01$ according to the LSD test. Small letters in rows and columns in each year indicate significant differences in the interaction between fertilization treatment and hybrid. Capital letters in rows and columns in each year indicate significant differences among fertilization treatment and hybrid, respectively. SEM—standard error of the mean. **—significant at $p < 0.01$. ns—not significant.

In 2021, the average yield for all hybrids (6091.7 kg·ha^{-1}) was significantly lower when only mineral fertilizers were used (F-treatment) than in the two other treatments where lime was applied, whereas there was no significant difference between yields in LF- (7374.9 kg·ha^{-1}) and LMF-treatments (7478.2 kg·ha^{-1}). Therefore, liming led to a significant increase in the yield of the investigated hybrids. The average yield ranged from 6903.1 kg·ha^{-1} for ZP 606 to 7105.9 kg·ha^{-1} for NS 6030. The hybrid NS 640 had the best yield response to the application of only mineral fertilizers, 6601.0 kg·ha^{-1}. This hybrid is the most commonly used and cultivated, and it had significantly higher yields only in relation to ZP 606 (5283.0 kg·ha^{-1}). The hybrid ZP 606 showed the greatest response to liming combined with mineral fertilizers compared to the other investigated hybrids, and achieved the highest yield of 7658.8 kg·ha^{-1}. This increase in yield was significant only in relation to the hybrid NS 640 (6977.7 kg·ha^{-1}). The hybrid ZP 606 achieved the highest yield after the combined treatment with manure, lime and mineral fertilizers, 7767.5 kg·ha^{-1}. This increase in yield in this research year was not statistically significantly higher than the yields achieved by the other hybrids. The hybrid ZP 606 achieved the highest yield in 2021 under two limed treatments, whereas it had the lowest yield under F-treatment. In contrast, the hybrid NS 640 had the highest yield in F-treatment, whereas its lowest yields were in LMF- and LF-treatments.

3.4.2. Maize Yield in 2022

The second year was more favorable from a perspective of weather conditions than the previous one, as 29.6 mm more precipitation was measured in the growing season, compared with the long-term average. In 2022, the average yield of maize, regardless of fertilization options, was 9516.0 kg·ha^{-1}, i.e., 2500 kg·ha^{-1} more than in 2021 (6981.6 kg·ha^{-1}). The results obtained in 2022 indicate that there were statistically significant differences between fertilization treatments, on average for all hybrids, as well as between individual hybrids, on average for all fertilization treatments.

The application of 3 t·ha^{-1} of lime together with mineral fertilizers (N_{155}, P_{80}, K_{80}) led to a statistically significant increase in yield (9839.5 kg·ha^{-1}) on average for all hybrids compared to the application of only mineral fertilizers (8153.0 kg·ha^{-1}), but the increase was significantly lower than under LMF-treatment with 30 t·ha of manure, and the obtained yield was 10,555.5 kg·ha. Averaged across all fertilization treatments, the highest average grain yield was achieved by NS 6030 (9752.9 kg·ha^{-1}), and this increase was significantly higher than in NS 640 and ZP 666, but not significantly higher compared to ZP 606 (9557.5 kg·ha^{-1}). The lowest grain yield regardless of the treatment was achieved by the hybrid NS 640, and its yield was not significantly lower only in relation to the hybrid ZP 666. In 2022, different hybrids performed differently in different treatments. The hybrid NS 640 (8612.7 kg·ha^{-1}) responded best to the application of only mineral fertilizers, as in 2021. Nevertheless, in 2022, its yield was statistically significantly higher than in all other hybrids. The applied lime with mineral fertilizers resulted in the lowest yield of the hybrid NS 640 (9348.5 kg·ha^{-1}), which was significantly lower than in all other hybrids. In LF-treatment, NS 6030 achieved the highest yield (10,135.8 kg·ha^{-1}), and liming coupled with mineral fertilization gave a significant increase compared to NS 640, but not compared to ZP 606 and ZP 666. The lowest yield in LMF-treatment was achieved by the hybrid NS 640 (9830.67 kg·ha^{-1}), and this reduction in yield was significantly lower than in the other hybrids. This hybrid again had the weakest response to the addition of lime and manure jointly with fertilizers. The hybrid NS 6030 achieved the highest yield in LMF-treatment (11,056.0 kg·ha^{-1}), which was significantly higher than in NS 640 and ZP 666, but not compared to the hybrid ZP 606 (10,943.5 kg·ha^{-1}). The hybrid ZP 606 indicated the necessity to apply amelioration measures, primarily liming, which was confirmed by its yield in 2022 achieved after liming, and after the addition of organic fertilizers. This hybrid had the highest relative yield increase compared to F-treatment, which was 26.6% in LF-treatment and almost 40% in LMF-treatment. In 2022, the most productive hybrid was NS 6030 in LMF-treatment, unlike in 2021, when the most productive hybrid was ZP 606, in the same treatment.

The results of the first two years of the research indicate that in both years the hybrid NS 640 had the highest yield, and ZP 606 had the lowest yield, when only mineral fertilizers were applied. In contrast, after the addition of lime and mineral fertilizers, as well as after the application of lime, manure and mineral fertilizers, the hybrid NS 640 obtained the lowest yields in both years. This indicates that the hybrid NS 640 is more tolerant to bad conditions of pseudogley soils, as well as that it can achieve satisfactory yields without the application of amelioration measures, first of all liming. This is probably the reason for the great demand for this hybrid by agricultural producers, even though it is an older generation hybrid, and we know that newer hybrids with a much higher genetic fertility potential have been created. On the other hand, the hybrid ZP 606, as the leader of the newer generation of domestic hybrids of maize, achieved the lowest yield without liming, which indicates that this hybrid, despite its high genetic fertility potential, necessitates improvement of the poor agrochemical properties of the soil.

3.4.3. Maize Yield in 2023

The third year of the research was the most favorable from the point of view of the amount and distribution of precipitation in the growing season. In this year, the highest average yield of all investigated hybrids was achieved. The highest amount of precipitation was measured in June and July, when there was the highest evaporative demand. In 2023, the average grain yield of maize, regardless of fertilization regime, was 9985.0 kg·ha^{-1}, i.e., 3000 kg·ha^{-1} more than in 2021, and 469 kg·ha^{-1} more than in the favorable year 2022. The grain yield on average for all hybrids in the LMF-treatment was 11,117.0 kg·ha^{-1}, which was significantly higher than under the treatment with only mineral fertilizers (8054.7 kg·ha^{-1}), and treatment with lime and mineral fertilizers (10,783.4 kg·ha^{-1}).

The hybrid ZP 606 (10,323.6 kg·ha^{-1}) had the highest grain yield on average for all treatments, and this increase was significantly higher than the yields of the hybrids ZP 666 and NS 640, but not compared to the hybrid NS 6030 (10,136.0 kg·ha^{-1}), which was also significantly higher than NS 640 and ZP 606. The hybrid NS 640 achieved a significantly higher yield, 8724.2 kg·ha^{-1}, than the yields of the other hybrids in F-treatment. The obtained results confirm the findings of the two previous years regarding the tolerance of the hybrid NS 640 to unfavorable pseudogley conditions and its successful cultivation on such soils without amelioration. The hybrid NS 6030 had the lowest yield when only mineral fertilizers were applied, 7679.9 kg·ha^{-1}, which was significantly lower than the yields of NS 640 and ZP 666. Liming together with mineral fertilization resulted in the lowest yield of NS 640, which was significantly lower than in the other hybrids, which is identical to the results obtained in the first two years of the research. The hybrid NS 6030 had the highest yield (11,289.4 kg·ha^{-1}) after liming, followed by ZP 606, which also gave a significantly higher yield than NS 640 and ZP 666. The results obtained, as in the two previous study years, once again showed a good response of the hybrid ZP 606 to the application of lime together with mineral fertilizers, and pointed out the need for proper fertilization and practices to repair pseudogley soil in order to achieve satisfactory yields. The yield increase compared to F-treatment was 44.2% for ZP 606, and 47.0% for NS 640. The combined use of lime, manure and mineral fertilizers led to the highest yield in all investigated hybrids. The hybrid ZP 606 had the highest yield in 2023, 11,969.7 kg·ha^{-1}, which was significantly higher than all other hybrids. The yield increase in this hybrid compared to F-treatment was as much as 53.9%, i.e., it was higher by almost 4200 kg·ha^{-1}. In LMF-treatment, the hybrid ZP 606 was followed by the hybrid NS 6030 with a grain yield of 11,438.8 kg·ha^{-1}, which was also significantly higher than the yields of NS 640 and ZP 666. The results obtained in LMF-treatment confirm the results of the two previous years of the research for NS 6030, i.e., the positive response to the application of lime, manure and mineral fertilizers (47–49% increase in yield), which indicate the need of this hybrid for pseudogley reclamation. The same applies to the hybrid ZP 606 in this year. In all three years of the research, the highest yields were achieved after the combined application of lime and mineral and organic fertilizers.

4. Discussion

4.1. Effect of Liming on Soil Characteristics

In the era of climate change and the enhanced importance of environmental protection, the amelioration (reclamation) of acid soils is an important factor in resource preservation, and therefore it is very important to accurately determine the doses of applied amendments which reduce the content of mobile forms of toxic Al and other compounds [28], and which improve soil properties and promote the growth and development of cultivated crops. Regardless of the management treatment, the addition of lime improved the main chemical properties of pseudogleys after three years, with evident benefits up to a depth of

0.30 m (Table 3). The results of the three-year experiment are in agreement with the results obtained by researchers in different climatic zones, and rarely differ from them.

In a study in Ethiopia, ref. [29] investigated the effect of different doses of liming material and its application method on maize yield and soil properties, and they determined that 3.5 t·ha^{-1} of calcareous material significantly increased the soil reaction compared to treatments with less than 1 t·ha^{-1} material, as well as that base saturation was increased from 69.8 to 75.6% with 3.5 t·ha^{-1} of added lime. In contrast, in our conditions, the base saturation increased significantly in LF- and LMF-treatments, compared with F-treatment, by 61 and 75%, respectively (Table 3), which is significantly higher than [19] where the increase was approximately 21% after a two-year trial. This difference in these two studies is related to the initial soil reaction and base saturation, which in the previously published study [19] was 5.60 and 57%, respectively, whereas in the current research the pH in H_2O = 5.04, and base saturation was approximately 50% (Table 2). The increase in the content of exchangeable bases due to the addition of calcareous material has been confirmed in many studies [30,31]. Adane [32] obtained a significant increase in soil pH (from 5.03 to 6.72) by applying 3.75 t·ha^{-1} of lime, which is a greater increase in pH compared to 1.2 pH units after our three-year experiment. Kimiti et al. [33] applied 2 t·ha^{-1} of lime to significantly increase soil pH by 10.6% after the first year of application and 17.7% after two years of application. In our case, there were no significant changes in F-treatment, while in LF and LMF-treatments the pH in KCl increased by 35 and 37%, respectively.

In a five-year barley experiment in Western Ethiopia, ref. [31] determined that the application of 2.2 t·ha^{-1} of calcareous material led to an increase in the soil reaction from 4.52 to 5.30. After five years of research, soil pH slightly increased in the control treatment, whereas in our experiment the application of only mineral fertilizers led to a slight decrease in active acidity. In this regard, ref. [34] in a long-term study (28 years) determined that the effects of the long-term use of mineral fertilizers in South China led to a 15% decrease in pH value. Therefore, on the one hand, mineral fertilizers led to further soil acidification, whereas on the other, the addition of lime after 8 years of application significantly reduced mobile aluminum, which is in agreement with our results. The results of soil chemical analysis in the Czech Republic showed that over 25% of arable soils have a pH value lower than 5.5 [35], and further soil acidification can be attributed to intensive fertilization with only mineral fertilizers, especially nitrogen, and insufficient application of manure and lime. Similarly, in an 18-year fertilization experiment, in an intensive farming system, urea significantly reduced soil pH and was confirmed as the major cause of intensified acidification of the red soil in southern China, and the pH decrease was accompanied by increased exchangeable acidity, which was dominated by exchangeable Al^{3+}, and reduced amount of exchangeable Ca^{2+} and Mg^{2+} in the soil [36]. Adversely, in the same experiment, continuous annual applications of manure as 100 or 70% of total N source resulted in either increased or unchanged soil pH during the 18-year study period. In a similar experiment, the application of livestock manure without liming stabilized soil acidity and reduced mobile aluminum, while increasing the availability of phosphorus after 22 years of research in the Czech Republic [37], at two out of five experimental locations, on stagnic cambisols. Therefore, the addition of manure can increase soil pH due to the alkalinity of the manure itself [38]. The long-term use of manure reduced the exchangeable aluminum content by 15–30% compared to the application of only mineral fertilizers [39].

Trivalent aluminum is the most abundant form at low pH and has the greatest impact on plant growth by occupying most of the negative charges in acidic soils [40]. Unlike fulvic acids, humic acids bind organo-mineral complexes more strongly despite their own relatively high acidity, and not only do they not acidify the soil solution with aluminum compounds, but they also play the buffering role with the acidity caused by aluminum. To

maintain Al^{3+} at a level that does not endanger the development of plant roots, the pH of the soil must be above 5.0 [41]. In our experiment, at this soil reaction, the content of aluminum was determined (Table 2). The obtained content is potentially harmful to plants, and calcification, in addition to increasing the portion of bases and reducing acidity, also reduced mobile aluminum several times, and increased available forms of phosphorus and potassium (Table 4), which ultimately also reflected on the yield of maize. In [28], the implementation of 40 t·ha^{-1} of manure on a luvisol variable similar chemical, but slightly different physical properties compared to the pseudogley in our study, increased the pH and reduced the hydrolytic acidity, pointing out that aged cattle manure can also reduce acidity due to its pronounced buffering capacity and content of adsorbed base cations. In the same work, the highest contents of mobile aluminum occurred in the control treatment and in the treatment where only mineral fertilizers were applied, where the content of easily mobile aluminum slightly increased, whereas the application of 2.5 t·ha^{-1} of lime on the loamy acid luvisol reduced the aluminum content below the toxicity limit for plants after a four-year period. Mobile aluminum in a five-year trial by [31] decreased from 1.19 to 0.32 cmol·kg^{-1}, which was 3.71-fold less, and is similar to our results of 2.55-fold less in LF-treatment and 4.19-fold less in LMF-treatment. Tao et al. [42] found that the long-term application of mineral fertilizers tended to acidify the upper layer of the soil, which resulted in higher mobility of Al ions. By liming at 5 t·ha^{-1} and 20 t·ha^{-1}, ref. [43] increased the pH of the soil from 4.75 to 5.28, while also increasing the availability of phosphorus and magnesium and reducing the content of manganese and iron, compared to the control.

Many authors [29,44] stated that the increase in soil pH by liming also affected the availability of phosphorus. This is in the agreement with our results where liming almost doubled the content of available phosphorus compared with the treatment where it was not performed (Table 4). Negese et al. [45] significantly increased available phosphorus in the soil compared to the control by applying lime and vermicompost. As in our experiment, the highest phosphorus content was obtained by the combined application of lime and an organic amendment, because after three years of liming, the phosphorus content in F-treatment was only 6.6 mg·100 g^{-1} in the LF- and LMF-treatments. Hence, liming is certainly one of the most effective practices for mitigating acidity and increasing the availability of phosphorus in acidic soils [46]. Wen et al. [47] reported an increase in soil pH and organic matter content with the long-term (22 years) addition of manure on ferralic cambisols. Crusciol et al. [48] also improved soil pH and base saturation by applying 6000 kg·ha^{-1} of lime, which is in agreement with our results. They also increased the content of organic matter, which was in our experiment the case only in LMF-treatment (Table 3), whereas SOC decreased after the application of lime with mineral fertilizers, or the application of only mineral fertilizers. This can be explained by the fact that, under the conditions of restoration of the soil chemical properties, a faster mineralization of organic matter occurred, because lime promotes microorganisms in the soil, which helps the decomposition of organic residues [49].

Ejigu et al. [50] investigated the effects of two doses of lime on soil characteristics, and determined that the application rate of 3 t·ha^{-1} of lime is economically justified and optimal for mitigating acidity and increasing nutrient availability and crop yield, which is also confirmed in our study by the application of the same amount of lime, which reduced total and exchangeable acidity, increased the content of available phosphorus, decreased the content of mobile aluminum, and achieved the highest maize yield in a three-year period. According to some authors, the economic benefits of liming should be investigated [51] and according to others, farmers should not only seek profit, but should also look to soil restoration [52]. The best lime application approach for acidic soils is to maintain a

proper crop rotation and introduce plant species that are tolerant to soil acidity (lupins, potatoes), in order to ensure that the effect of lime lasts as long as possible, because lime, which is cheaper than mineral fertilizers, can reduce plant production costs and increase yields [53]. Hence, liming is the main strategy to increase soil pH, and it is also one of the least expensive practices for managing acidity [54].

4.2. Effect of Fertilization and Liming on Maize Grain Yield

Although the grain yield of the investigated maize hybrids was influenced by meteorological conditions, liming increased the yield compared to the no-lime treatments. Moreover, the highest yield increase in all hybrids was achieved by applying manure in combination with lime and mineral fertilizers (Table 5). The yield increase in all hybrids was the least pronounced in 2021, the year with the least rainfall in the growing season. In the second and third year of the experiment, the average increase in the yield of all hybrids was higher, but the increasing tendency was also explained by the achieved level of changes in the soil after liming and manure application. Therefore, a slightly more favorable structure, reduced acidity, increased base saturation, an increased content of available phosphorus, a lower content of mobile aluminum, i.e., all lime-induced changes were reflected in the yield of maize hybrids. The effect of fertilizer application is usually greater on soils with less fertility, but is even more pronounced on extremely acidic soils, especially those with an increased portion of Al^{3+} ions in total acidity. The obtained results of maize yield increase do not fully agree with [19] on the pseudogley in the vicinity of Kraljevo, because they achieved a smaller yield increase, and not significantly different, in their LF-treatment. In Serbia, there is a gap of almost 25 years in research on the benefits of liming, although the acidification process has progressed in Serbian soils, among other things due to the application of only mineral fertilizers and reduced use of manure. In addition, the average yield of maize on these acid soils did not increase, despite the constant increase in the doses of fertilizers, especially nitrogen, and the introduction of new hybrids with greater genetic potential into the maize production. This is an important reason why liming as a sustainable and amelioration practice in Serbia requires a thorough approach. The international scientific community deals with the problems of acidic soils and the effects of liming on yield, but there are not much data on the tolerance of different maize hybrids to increased concentration of mobile aluminum and poor agrochemical properties of acidic soils.

The application of 3 t·ha^{-1} of lime (73% CaO + 2–3% MgO) in Slavonia, ref. [43] increased maize yield in a two-year period by 33–35%, and this increase was greater in the second year of the study. In our experiment, the tendency to increase the grain yield of all four examined hybrids was higher in the second year, and especially in the third year (Table 5). By applying 10 t·ha^{-1} of hydrated lime powder and phosphorus fertilizer, ref. [55] obtained a 31% higher yield (four-year average) on the pseudogley soil of Republika Srpska for monoculture maize, and a significantly smaller yield increase was observed where only three doses of phosphorus fertilizer without lime were applied. In our experiment, after three years of research, the average yield increase in LF-treatment compared to F-treatment was 25.9%, and in LMF-treatment 30.8% (Table 5). However, there are significant differences between hybrids. Kimiti et al. [33] combined 2 t·ha^{-1} of lime and manure with mineral fertilizers and increased maize yield compared to the individual application of only lime and only manure on high acidity soils in central and western Kenya regions, which is also in agreement with our results. The application of mineral fertilizers and lime in the southern region of China significantly reduced the acidity of cambisol and increased yield compared to the treatment where only mineral fertilizers without lime were applied in a six-year study conducted by [56], who investigated the yield of wheat and maize in crop

rotation. In a recently completed two-year experiment, ref. [19] found an increase in maize yield in a liming treatment by 9 and 4.4% compared to F-treatment, but without statistical significance. This can be explained by much better initial soil conditions in this experiment before the application of the amendment (pH approximately 5.6) as well as by the high amount of precipitation that affected the absorption of nutrients.

On an acidic soil with an increased content of mobile aluminum, ref. [57] investigated the yield of maize and soybean by applying different doses of liming material and found a significant increase in yield compared to the non-limed treatment. At the same time, one maize hybrid gave a significantly higher yield than the other genotype in the treatment without lime; therefore, we can talk about the tolerance of different maize genotypes to mobile aluminum. This was also recorded in our results, where the hybrid NS 640 had a significantly higher yield (from 6.5 to 12.7%) when the concentration of mobile aluminum was the highest, i.e., in the treatment where only mineral fertilizers were applied (Table 5). By applying dolomite lime on topsoil, ref. [58] determined that higher doses of lime increased soil fertility and the concentrations of calcium and magnesium at greater depths, i.e., in the driest year of the study, when higher doses of lime were applied, maize had better nutrition, a better developed root system, a higher concentration of chlorophyll and higher water use efficiency. Although we did not measure root development in our treatments, the effect of lime on maize growth compared to the treatment where only mineral fertilizers were applied was visible. Brozović et al. [59] similarly reported that liming significantly increased maize yield. During their experiment, less precipitation was recorded compared to the long-term average, and the applied lime significantly increased maize yield on a similar pseudogley. The authors found that the liming material reduced acidity and mobile aluminum, and that it contributed to the development of the root system, which further contributed to a better absorption of nutrients and water, and therefore led to better maize tolerance to drought, and hence increased yield. In the experiment with different doses of nitrogen fertilizer, with and without liming, ref. [48] reported that lime application significantly increased maize yield in all lime + nitrogen fertilizer treatments compared to no-lime treatments. In a long-term experiment, ref. [34] also found a significant increase in maize yield in treatments with the application of lime compared to treatments fertilized with different combinations of mineral fertilizers.

By testing 12 parental maize lines for soil acidity, where the pH was 4.3, and adding $CaCO_3$ to an acidity of pH = 6.5, ref. [22] determined, by measuring root growth and other indicators, that there are differences in hybrids and that there are tolerant, moderately tolerant and sensitive maize genotypes. Germplasm screening revealed that two of the investigated maize hybrids had the highest relative root growth, indicating their tolerance to the level of soluble aluminum [21]. Aluminum toxicity in maize led to a significant yield reduction of 18.7% for lines and 14.7% for hybrids during two years of cultivation [60]. Raboin et al. [61] examined the impact of biochar (50 t·ha^{-1}) and dolomite (3 t·ha^{-1}) on the yield of maize and beans after five years of application and concluded that, due to the increase in soil pH and the reduction in mobile aluminum, the yield of maize increased significantly. The application of dolomite is more practical and profitable in comparison to the equivalent amount of biochar required to improve the chemical properties of the soil. Cai et al. [36] concluded that for the restoration of acidic soils, i.e., increasing pH and decreasing mobile aluminum and increasing available phosphorus, the best combination is lime and pig manure.

The hybrid ZP 606 achieved an average yield increase of 42.8% for all limed treatments, in three years of research. It is followed by NS 6030 with an average relative yield increase of 33.4%, and further by ZP 666 with 25.8%, which is also a high increase (Table 5). The yield increase in NS 640 after liming was 11.4%, and the justification of pseudogley amelioration

is questionable. The yield of the hybrid ZP 606 on LMF-treatment was the highest achieved in a three-year period, while the lowest yield for all three years was achieved in 2021 with the same hybrid on F-treatment. Considering the use of mineral fertilization alone, the results obtained for all three years show that the hybrid NS 640 was the most productive, indicating its tolerance to unfavorable agrochemical properties of pseudogley and its modest requirements with respect to soil conditions. Based on that, this hybrid can be recommended to producers for growing on this type of soil, without applying amelioration practices, primarily liming.

5. Conclusions

Pseudogley soils are characterized by poor chemical and physical properties, which, together with hydrological conditions, limit them in terms of obtaining high maize yields. Regular application of usual doses of mineral fertilizers does not increase the yield of maize to a satisfactory extent, although the doses of fertilizers are increased, and at the same time they deteriorate the chemical soil properties. By applying calcareous material with the usual doses of fertilizers, as well as by adding manure to the calcareous material and fertilizers, the yields of four maize hybrids were significantly increased. This increase in yield was accompanied by an improvement in soil chemical properties, i.e., increased soil reaction and base saturation, mobilization of readily available phosphorus and immobilization of aluminum. The hybrid NS 640 was the most productive hybrid when mineral fertilizers were applied without calcareous material and manure. This hybrid has higher tolerance to the unfavorable agrochemical properties of pseudogley and more modest requirements, and based on that, it can be recommended to producers for use without applying amelioration practices. On the contrary, the same hybrid achieves significantly lower yields than the other hybrids when lime and manure are applied. The hybrids NS 6030 and ZP 606 achieved statistically significantly higher yields than the other hybrids under lime and manure treatment, which indicates the need for adequate fertilization and ameliorative practices to restore pseudogleys in order to achieve satisfactory yields of these hybrids. The future research should be directed into the investigation of the responses of major crops grown in the broader area to similar fertilizer practices. It is not advisable to grow alfalfa (*Medicago sativa* L.) on acidic soil, but traditionally, it presents one the major source of good-quality forage in the broader area. Also, the hilly terrains of this region are well known by growth and production of raspberries (*Rubus idaeus*) on luvisol soil type and the application of lime could contribute to better production of this very important fruit in Serbia. Further, it would be very important to investigate the effects of different liming materials found in the vicinity, on crops, because of the various ratios of calcium and magnesium in them, and to find appropriate doses of lime, appropriate size of liming material, and the most feasible type of lime application/incorporation.

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