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Research Article

Impact of lime and NPK fertilizers on yield and quality of oats on pseudogley soil and their valorisation

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Abstract

In order to determine the effect of fertilization, environment, and their interactions on the yield and oats yield components. Five fertilization treatments (T1-control, T2-80 kg N ha^{-1}, T3-120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} of lime and T5-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} of lime + 30 t ha^{-1} of farmyard manure) were examined during three growing seasons in Kraljevo location in Western Serbia. Grain yield (GY), 1000 grain weight (TGW), hectolitre weight (HW), plant height (PH), panicle length (PL), number of grains per panicle (NGP) and protein content (PC) were analysed. The aim of the study was to determine the effect of organic and mineral fertilization and calcification on the yield and oats yield components. On average, for all fertilizer variants, during the three-year trial, the highest yield of oats 3802 kg ha^{-1} was obtained in the fertilizer variant with the combined application of NPK fertilizers, lime and manure. Positive highly significant correlation, during in the study trial were found between yields with PH, PL and NGP. Negative and highly significant dependencies were found between protein content with GY, PH and NGP. The results of these studies indicate the importance of rational introduction of adequate quantities of fertilization, calcification and humization in order to make oats as profitable as possible in the agro-ecological conditions in Pannonian Environments.

Keywords: farmyard manure; fertilizer; grain quality; lime; oats; protein content; yield

Introduction

Oat is a plant species that has significantly less fertilization requirements than other small grains. This plant species has a higher power of absorbing nutrients from soils that are not fit for cultivation of wheat, such as acidic soils, as well as other poor soils of marginal value. In recent years, total production and areas under

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oats, both in the world (Khan *et al.*, 2014) and in the Republic of Serbia (Jelic *et al.*, 2013), have been diminishing sharply. Today, in the world, according to FAO data, in 2018, oats is grown annually on an area of 9.85 million ha, with an average yield of 2.341 t ha^{-1}, while in the Republic of Serbia it is cultivated on an area of 26.111 ha, with a slightly higher yield 2.861 t ha^{-1} (FAO, 2020).

Oat fertilization is a very important technological operation for achieving high grain yields. Oats uses very hard soluble nutrients from the soil very well. It responds well to fertilization, especially nitrogen (Monjezi-Zadeh *et al.*, 2018; Vasileva and Kostov, 2018). With the application of optimal amounts of fertilizer on most soils, oats give high grain yields (Nawaz, 2017). Oat plants are a major consumer of nitrogen and potassium, however, when fertilizing with nitrogen, caution should be exercised as stronger crop lodging can occur (Tomple and Hwan, 2018). Starting from the stated yield standards of 3.0 t ha^{-1} of grain, Jelic *et al.* (2013), point out that about 80 kg ha^{-1} of nitrogen should be used; 40-50 kg ha^{-1} of phosphorus and about 40 kg ha^{-1} of potassium.

Due to the good intake power of the root, oats make excellent use of nutrient residues after the pre-harvest crop and in crop rotation it often comes last, however, high grain yields cannot be expected in such crop rotation. The requirements of oats in relation to soil compared to other cereals, except rye, are modest (Zielinski *et al.*, 2017). Although it thrives on poorer soils with slightly reduced yields, oats nevertheless achieve higher yields on more fertile lands (Tomple and Hwan, 2018). Panasievicz *et al.* (2017), find that nitrogen application significantly affects the protein content of oat grains, especially when using large doses of this nutrient (100 and 150 kg N ha^{-1}). Many authors point out that different oat genotypes (winter and spring) differ in chemical composition, and especially in protein content (Amanullah and Stewart, 2013; Khan *et al.*, 2014; Mut *et al.*, 2018). The quality and chemical composition of oat grains are closely related to the fertility of this crop species, which is a significant feature in terms of the cost-effectiveness of its cultivation in general and its use as a forage plant (Jelic *et al.*, 2013; Brunava *et al.*, 2014; Jordanovska *et al.*, 2018).

Although oats have a stretched and relatively uniform rhythm of nutrient uptake during vegetation, most nutrients are still required during stem elongation and in the panicle occurrence phase (Mahadevana *et al.*, 2016). Thus, the amounts of applicable nitrogen, phosphorus and potassium nutrients depend on the resistance of the cultivated oat varieties to crop lodging and low temperatures, soil fertility, soil physical properties, agro-ecological conditions of the area, planned yield and economic power of the producer (Maral *et al.*, 2013; Krishna *et al.*, 2014; Zielinski *et al.*, 2017; Devi *et al.*, 2019; Szatanik-Kloc *et al.*, 2019). For high yields of oats, complex NPK fertilizers need to be introduced with the prolonged action of manure applied for the preceding crop (Jelic *et al.*, 2013).

In the Republic of Serbia, especially in its central part, the production of cereals is mainly carried out on soils with acidic and extremely acidic reactions, low quality structures that are poor in organic matter (Jelic and Milivojevic, 2015). On acid reaction soils, a universal fertilization system does not exist due to the very uneven physical and chemical properties of these soils. Therefore, the application of fertilizers on acid soils must be approached in a much more rational and multi-faceted manner.

Bearing in mind the necessity of applying pedomeliorative measures and the use of larger quantities of fertilizers on acid soils, there is a need to review and modify the existing fertilization systems. For these reasons, the aim of the study was to determine the effect of the application of different fertilization variants (NPK, lime, and manure) on the yield parameters and quality of oat grains on pseudogley soil. In addition, the aim of the research was to determine the optimal use of fertilizers to achieve profitable production of oats in the Western Serbia region.

Materials and Methods

Experimental design

Field experiments were performed on the experimental field of the secondary agricultural-chemical school "Dr. Đorđe Radić" in Kraljevo (43°43′00′′N, 20°40′60′′E, 198 m above sea level) during three growing seasons (2015, 2016 and 2017) in dry crop conditions, with the aim of analysing the yield and quality of oat grains in Western Serbia. Trials were arranged according to a randomized scheme in five repetitions. Trial treatments included different fertilization variants: T1-control, T2-80 kg N ha^{-1}, T3-NPK (120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}), T4- $N_{120}P_{80}K_{80}$ + 5 t ha^{-1} of lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} of manure + 5 t ha^{-1} of lime (factor A) and different growing seasons: Y_1-2015, Y_2-2016 and Y_3-2017 years (factor B). NPK fertilizer formulation (15:15:15) was used in the experiment in pre-sowing soil preparation. In early March 2015, non-hydrated CaO lime, 99% pure, was applied for calcification of the soil and incorporated at a depth of 30 cm. The spring oat has been preceded by maize in all seasons. During the vegetation period of oats to protect crops from *Lema melanopus* L. was used preparation Fastac 10 EC (0.15 l ha^{-1}). Fertilization was carried out in 2-3 leaf stage, and nitrogen was applied in the form of ammonium nitrate (AN, 33% N).

The area of the elementary plot was 500 m^2 (25 m × 20 m). The spring oat variety Slavuj originating from the Kragujevac Centre for Small Grains was selected as the material for the experiment. The sowing was performed within the optimum agrotechnical period (March 10, 2015, March 7, 2016, and March 11, 2017) at 12 cm row spacing, with a sowing density of 500 germinating grains per m^2. The trial was designed in randomized blocks with five replications. Conventional production technology was applied. The crops were harvested at full maturity stage (dates of harvesting 10 July 2015, 6 July 2016 and 14 July 2017) and the grain yield (GY, t ha^{-1}), 1000 grain weight (TGW, g), hectolitre weight (HW), plant height (PH), panicle length (PL), number of grains per panicle (NGP) and protein content (PC) were quantified. Grain yield was measured for each plot and converted to grain yield in t ha^{-1} based on 14% grain moisture, after which a sample was taken for analysis of TGW, HW and PC of the grain. Thousand grain weight was determined using an automatic seed counter. Hectolitre weight was determined by a Schoper's scale, 0.25 l capacity. The Kjeldahl method was used to determine the nitrogen content of the oat grain, while the crude protein content of the grain was obtained by multiplying the total nitrogen by a factor/coefficient of 6.25. Immediately before harvest, a sample of 20 plants was taken from each plot to determine PH, PL and NGP. Standard grain sampling techniques were used in the research.

Soil analysis

The trial was performed on pseudogley soil, of unfavourable physical characteristics, of poor water-air regime with frequent water or air deficiencies. According to the results of agrochemical analysis, the soil is acidic (pH in H_2O 5.42 and pH in KCl 4.46), poor in humus (2.19%), poor in available phosphorus (<10 mg 100^{-1} g of soil) and medium provided with readily available potassium (13-18 mg 100^{-1} g of soil). The soil was analysed using chemical methods: soil pH was determined in a 1:2.5 soil 1 M KCl suspension after a half-hour equilibration period; hydrolytic acidity by Ca acetate extraction using Kappen's method; the sum of exchangeable basic cations by Kappen's method; humus content by Kotzmann's method; total nitrogen by Kjeldahl, and available P_2O_5 and K_2O levels by the Egner-Riehm Al method.

Statistical analysis

Experimental data were analysed by descriptive and analytical statistics using the GenStat (2013) for PC/Windows 7, and significance of differences between means were determined according to Tukey test (P = 0.05) which represents the standard statistics for the experiment. Recorded data are presented as mean values with computed standard deviation (Sd). The Pearson's correlation coefficient was obtained were tested at the 5% and 1% levels of significance.

Environmental variables

The area of Kraljevo is located in the Čačak-Kraljevo valley that belongs to the Western Morava river region, in Serbia. It is surrounded by a large number of mountain ranges and their hills through which the wide river valleys of the West Morava, the lower Ibar and the lower Gruža intersect. It is located at 20°40'60" E longitude and 43°43'00" N latitude. The soil of the studied area is in a zone of temperate continental climate, with uneven distribution of precipitation by months. Based on the data of meteorological stations in Kraljevo, in the years in which the researches were carried out, differed from the long-term average characteristic of the area. The average air temperature was higher than the annual average by 0.58 °C in 2015, by 1.0 °C in 2016 and by 1.46 °C in 2017 (Table 1).

The total amounts of rainfall were above the perennial average in the surveyed growing seasons (2015, 2016, 2017), with a rather uneven monthly distribution. Weather conditions in the growing period in 2016 were marked by high rainfall during May, while rainfall in April was significantly lower. Variable and moderately warm weather, with less precipitation than average, marked June 2016 and 2017 (Table 1).

Table 1. Precipitation sum and average monthly temperature in Kraljevo, Serbia

Year	**Months**					**Average**
	III	IV	V	VI	VI	
Mean monthly air temperature (°C)						
2015	6.3	11.6	17.6	19.7	24.6	15.96
2016	7.8	14.1	15.5	21.3	23.2	16.38
2017	10.3	11.3	16.2	22.4	24.0	16.84
30-year average	6.5	11.7	16.2	19.1	23.4	15.38
The amount of rainfall (mm)						
2015	163.5	64.2	91.2	89.7	9.3	417.9
2016	157.9	39.9	135.9	48.6	29.1	411.4
2017	57.7	82.1	99.9	56.2	35.2	331.1
30-year average	44.7	65.1	74.9	86.5	38.8	310.0

Temperature variations on average were higher in the third compared to the first and second seasons. During the run of the experiment (2015-2017), the differences between the mean precipitation values and the perennial average in the first and second years of the study were the highest in March and May.

Results

Grain yield

The average GY of spring oats for the whole trial over the three-year study period was 2.677 t ha^{-1}, Table 2. A significantly higher GY compared to the non-fertilizer variant was achieved on all fertilizer variants. On average for all fertilizer variants, the highest GY (3.802 t ha^{-1}) was obtained on the fertilizer variant T5 with 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}, 30 t ha^{-1} of manure and 5 t ha^{-1} of lime.

The combined application of lime, manure and mineral NPK fertilizers resulted in a significant increase in the yield of oats compared to the other fertilizer variants tested. Based on the analysis of variance, it can be concluded that the influence of growing season on GY was significant ($F = 3.426^{*}$), while the influence of different fertilization treatments on GY was highly significant ($F = 51.477^{**}$).

The highest average GY in the first year of testing was recorded for the fertilizer variant T5 (3.718 t ha^{-1}) and the lowest for control (1.085 t ha^{-1}) in Table 2. Based on the analysis of variance, it can be concluded that the growing season on GY was significant ($F = 6.475^{*}$), while the influence of different fertilization treatments on GY was highly significant ($F = 24.454^{**}$).

In the second year of testing, the highest GY of all fertilizer variants was achieved, also in this year, with the fertilizer variant T5 with 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}, 30 t ha^{-1} of manure and 5 t ha^{-1} of lime (4.454 t ha^{-1}). In 2016, GY was highly significant varied across treatments (Table 2).

In the second year of testing, the highest GY of all fertilizer variants was achieved, also in this year, with the fertilizer variant T5 with 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}, 30 t ha^{-1} of manure and 5 t ha^{-1} of lime (4.454 t ha^{-1}). In 2016, GY was highly significant varied across treatments (Table 2).

Average GY of spring oats for all fertilizer variants in 2016 was 3.082 t ha^{-1} and was close to the average GY in the Republic of Serbia (2.95 t ha^{-1}).

Table 2. Grain yield of spring oats in Kraljevo in Western Serbia

Fertilization	**Years**						**Average**	
	2015		**2016**		**2017**			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	1.085^{c}	0.441	1.363^{c}	0.383	0.910^{c}	0.204	1.119^{d}	0.383
T2	2.477^{b}	0.180	2.908^{b}	0.258	2.161^{b}	0.355	2.515^{c}	0.406
T3	2.631^{b}	0.466	2.989^{b}	0.555	2.574^{ab}	0.838	2.731^{bc}	0.622
T4	3.118^{ab}	0.576	3.694^{ab}	0.345	2.835^{ab}	0.433	3.216^{b}	0.565
T5	3.718^{a}	0.450	4.454^{a}	0.531	3.235^{a}	0.354	3.802^{a}	0.666
F	24.454^{**}		35.561^{**}		16.773^{**}		51.477^{**}	
P	< 0.001		< 0.001		< 0.001		< 0.001	
Years								
Average	2.606^{AB}	0.980	3.082^{A}	1.117	2.343^{B}	0.927	2.677	1.044
F	6.475^{*}		0.951		2.559		3.426^{*}	
P	0.014		0.334		0.116		0.038	

[1] T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

The average GY of all fertilizer variants in 2017 was 2.343 t ha^{-1}, which is 3.9% less than the average in the Republic of Serbia (Figure 1B). The highest average GY in the third year was the fertilization variant T5 (3.235 t ha^{-1}), and the slightly lower GY the variant T4 (2.835 t ha^{-1}). In 2017, GY was highly significant varied across treatments ($F = 16.773^{**}$) in Table 2.

1000 grain weight

The TGW, average for all fertilizer variants, was the highest in 2016 (29.50 g), slightly lower in 2015 (28.81 g) and the lowest in 2017 (27.32 g) in Table 3.

The fertilizer variants tested differed in terms of TGW. On average for all years, the highest TGW had the fertilizer variant T5 (29.71 g) and the lowest 27.88 g variant T2 (80 kg ha^{-1} N). Growing period in 2017 at the time of grain loading was marked by drought and high temperatures, which reduced the TGW.

The 1000 grain weight in the studied spring oats showed highly significant dependence on the year of study ($F = 10.488^{**}$) and very significant in the 2015 ($F = 14.930^{**}$) and 2016 ($F = 8.690^{**}$). Different fertilizer treatments did not significantly affect in the TGW (Table 3).

Hectolitre weight

The HW, average for all fertilizer variants, was the highest in 2016 (45.79 kg hl^{-1}) compared to 2017 (39.70 kg hl^{-1}) in Table 4.

Regardless of the year, control (T1) and variant with combined application of NPK fertilizer with lime and manure (T5) had the highest HW. However, observed by years, there is considerable disagreement on their differences. Hectolitre weight of grain in oats showed high dependence from the growing seasons (F = 121.499**) in Table 4.

Table 3. 1000 grain weight of spring oats in Kraljevo in Western Serbia

Fertilization	**Years**						**Average**	
	2015		**2016**		**2017**			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	28.98^a	1.141	29.98^a	0.432	26.30^a	0.758	28.42^a	1.782
T2	28.60^a	0.696	28.94^a	2.043	26.10^a	1.907	27.88^a	2.022
T3	28.84^a	1.167	29.32^a	0.811	27.46^a	4.421	28.54^a	2.613
T4	28.22^a	0.672	28.42^a	2.075	27.82^a	1.402	28.15^a	1.410
T5	29.42^a	0.996	30.82^a	1.018	28.90^a	0.828	29.71^a	1.216
F	1.081		2.100		1.253		2.110	
P	0.393		0.118		0.321		0.089	
Years								
Average	28.81^A	0.965	29.50^A	1.566	27.32^B	2.346	28.54	1.929
F	14.930**		8.690**		3.460		10.488**	
P	< 0.001		0.005		0.069		< 0.001	

[1] T1-control, T2- N$_{80}$, T3-N$_{120}$P$_{80}$K$_{80}$, T4-N$_{120}$P$_{80}$K$_{80}$ + 5 t ha^{-1} lime and T5-N$_{120}$P$_{80}$K$_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

Table 4. Hectoliter weight of spring oats in Kraljevo in Western Serbia

Fertilization	**Years**						**Average**	
	2015		**2016**		**2017**			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	44.80^a	0.417	46.63^a	0.769	38.95^a	0.864	43.46^a	3.454
T2	42.58^a	0.912	44.38^a	0.672	39.82^a	1.278	42.26^a	2.144
T3	42.90^a	2.659	46.37^a	2.518	39.74^a	0.576	43.00^a	3.432
T4	43.20^a	1.306	45.39^a	1.520	39.50^a	1.182	42.70^a	2.807
T5	44.40^a	0.359	46.19^a	0.939	40.50^a	0.348	43.70^a	2.524
F	2.380		1.980		1.860		0.587	
P	0.086		0.137		0.156		0.673	
Years								
Average	43.58^B	1.561	45.79^A	1.569	39.70^C	0.984	43.02	2.885
F	270.431**		110.221**		25.070		121.499**	
P	< 0.001		< 0.001		< 0.001		< 0.001	

[1] T1-control, T2- N$_{80}$, T3-N$_{120}$P$_{80}$K$_{80}$, T4-N$_{120}$P$_{80}$K$_{80}$ + 5 t ha^{-1} lime and T5-N$_{120}$P$_{80}$K$_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

The highest HW in the first year of testing had control T1 (44.80 kg hl^{-1} and the lowest variant T2 with 80 kg N ha^{-1} (42.58 kg hl^{-1}). In the second year of testing, T1 (46.63 kg hl^{-1}) had the highest HW. The highest HW in the third year had the fertilization variants T2 and T5 (39.82 kg hl^{-1} and 40.50 kg hl^{-1}, respectively), and the slightly lower value variant T3 (39.74 kg hl^{-1}). Analysing the variance between the fertilizer treatments tested, no statistical significance was found for the HW, Table 4.

Plant height

The highest value for PH of all fertilizer variants tested averaged significantly higher in 2016 (110.58 cm), slightly lower in 2015 (105.8 cm) and the lowest in 2017 (101.64 cm). The average three-year value of PH was 106.01 cm and ranged from 82.267 cm in control to 116.37 cm in the fertilizer variant with NPK, manure and lime in Table 5. Very high influence of mineral nutrition on the PH was found ($P<0.01$) among the tested fertilizer variants. Based on the analysis of variance, it can be concluded that the growing season, i.e. years of research did not significantly affect the height of the PH ($P>0.05$).

Table 5. Plant height of spring oats in Kraljevo in Western Serbia

Fertilization	**Years**						**Average**	
	2015		**2016**		**2017**			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	82.60^b	11.238	85.20^b	6.573	79.00^b	5.000	82.267^c	7.905
T2	106.00^a	10.075	111.00^a	8.775	101.80^a	10.756	106.27^b	9.960
T3	110.60^a	9.685	117.50^a	3.000	106.20^a	7.918	111.43^{ab}	8.394
T4	112.90^a	6.128	118.60^a	5.683	109.60^a	4.615	113.70^{ab}	6.391
T5	116.90^a	4.307	120.60^a	4.393	111.60^a	5.320	116.37^a	5.789
F	12.161**		29.623**		17.192**		46.465**	
P	< 0.001		< 0.001		< 0.001		< 0.001	
Years								
Average	105.80^A	14.699	110.58^A	14.445	101.64^A	13.680	106.01	14.559
F	5.048*		1.073		1.345		2.453	
P	0.029		0.305		0.252		0.093	

[1] T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

In 2015 year, the highest PH was found in variants with treatment T4 (112.9 cm) and variant T5 with NPK, manure and lime (116.9 cm). The assessment of significance of the obtained results shows highly significant differences between the PH and fertilizer variants ($F = 12.161^{**}$) and significant differences between the growing seasons on the PH ($F = 5.048^{**}$), Table 5.

Panicle length

The panicle length is a quantitative trait that represents the carrier of the genital branches. The panicle length in the second year of study (2016) was the highest at 26.82 cm, while the lowest value was found in the third year (23.38 cm). A significantly higher PL compared to the non-fertilizer variant was achieved on all fertilizer treatments.

In 2015, PL highly significant varied across treatments, was the highest at 26.40 cm in treatment T5 and the lowest the control T1 (21.40 cm). In the second year of study (2016) PL highly significant varied across treatments, was the highest at 29.70 cm in treatment T5 and the lowest the control (22.20 cm) in Table 6.

The highest average 3-year PL had the T5 variant (26.90 cm) and the lowest the control (21.50 cm). The results of the analysis of variance show that the growing season, i.e., the study three-year, have a very significant influence on the PL ($F = 9.785^{**}$).

The highly significance of the influence of mineral nutrition on the PL was determined ($P<0.01$). The highest PL in all three years of the study was found in the T5 fertilizer variant with NPK, manure and lime in Table 6.

Table 6. Length of panicle of spring oats in Kraljevo in Western Serbia

Fertilization	Years						Average	
	2015		2016		2017			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	21.40^{b}	2.043	22.20^{b}	1.037	20.90^{a}	2.073	21.50^{b}	1.742
T2	24.60^{ab}	1.387	26.50^{a}	2.398	23.20^{a}	1.037	24.77^{a}	2.112
T3	25.20^{a}	2.280	27.20^{a}	2.280	24.40^{a}	2.510	25.60^{a}	2.501
T4	25.80^{a}	2.049	28.50^{a}	3.041	23.80^{a}	2.775	26.03^{a}	3.165
T5	26.40^{a}	1.817	29.70^{a}	1.718	24.60^{a}	2.302	26.90^{a}	2.842
F	5.069^{**}		8.439^{**}		2.251		10.205^{**}	
P	0.005		< 0.001		0.099		< 0.001	
Years								
Average	24.68^{B}	2.512	26.82^{A}	3.294	23.38^{B}	2.442	24.96	3.088
F	17.593^{**}		3.442		6.671^{*}		9.785^{**}	
P	< 0.001		0.070		0.013		< 0.001	

T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

Number of grains per panicle

All fertilizer variants tested formed a significantly higher number of grains per panicle 115 in 2016 than 100 in 2017. The highest NGP in all three years of research, were recorded in following variant T5 fertilized with NPK, manure and lime and variant T4 fertilized with NPK. A significantly higher NGP compared to the non-fertilizer variant was achieved on all fertilizer variants in 2016 year ($F = 9.765^{**}$) and 2017 year ($F = 17.717^{**}$) and significant in the 2015 year ($F = 2.919^{*}$) in Table 7.

Table 7. Number of grains (panicle) of spring oats in Kraljevo in Western Serbia

Fertilization	Years						Average	
	2015		2016		2017			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	78^{a}	25.541	79^{c}	20.359	75^{c}	16.471	77^{c}	19.613
T2	98^{a}	9.209	102^{bc}	13.240	93^{b}	3.114	98^{b}	9.603
T3	113^{a}	42.312	122^{ab}	25.324	108^{ab}	7.616	115^{ab}	27.370
T4	117^{a}	5.891	135^{a}	12.462	111^{a}	5.128	121^{a}	13.184
T5	119^{a}	5.167	135^{a}	10.099	114^{a}	1.923	123^{a}	11.095
F	2.919^{*}		9.765^{**}		17.717^{**}		18.115^{**}	
P	0.047		< 0.001		< 0.001		< 0.001	
Years								
Average	105^{A}	26.166	115^{A}	27.066	100^{A}	16.716	107	24.227
F	5.123^{*}		0.511		1.749		2.403	
P	0.028		0.478		0.192		0.098	

[1] T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

The highest three-year average NGP was found in variant T5 (123) and slightly lower in variant T4 (121), while the lowest was in the control (77) in Table 7.

A very high influence in the three-year of mineral nutrition on NGP was found among the tested fertilizer treatments ($P<0.01$). Based on the analysis of variance, it can be concluded that the growing season, i.e. the year of the study, did not significantly affect the NGP ($P>0.05$).

Protein content of oat grain

The fertilizer variants tested varied significantly higher in the PC of the grain in Table 8. The highest PC in the study in 2015 year had T1 treatment (12.710%) and the lowest T5 treatment (9.904%). A significantly higher PC compared to all fertilizer treatments was achieved in the treatment T1.

Table 8. Protein content of spring oats in Kraljevo, Serbia

Fertilization	Years						Average	
	2015		2016		2017			
Treatments	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd	$\bar{x}$	Sd
T1	12.710^{a}	0.379	12.850^{a}	0.364	10.848^{a}	0.221	12.136^{a}	0.992
T2	12.036^{a}	0.331	12.158^{a}	0.897	10.634^{ab}	0.335	11.609^{a}	0.898
T3	10.786^{b}	0.705	10.984^{b}	0.380	10.140^{ab}	0.342	10.637^{b}	0.597
T4	10.204^{b}	0.597	10.562^{b}	0.227	9.834^{ab}	0.946	10.200^{b}	0.683
T5	9.904^{b}	0.405	10.362^{b}	0.658	9.634^{b}	0.760	9.967^{b}	0.657
F	28.480^{**}		18.470^{**}		3.802^{*}		21.304^{**}	
P	< 0.001		< 0.001		0.019		< 0.001	
Years								
Average	11.128^{A}	1.191	11.383^{A}	1.107	10.218^{B}	0.717	10.910	1.130
F	19.521^{**}		10.710^{**}		0.616		8.909^{**}	
P	< 0.001		0.002		0.436		< 0.001	

[1] T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01

In the second and third year of study, the highest PC was achieved by T1 treatment (12.850% and 10.848). The highest average PC of spring oat grains of all fertilizer variants was found in 2016 and amounted to 11.383%, while the lowest content was found in 2017 (10.218%) in Table 11. Based on the analysis of variance, it can be concluded that the different fertilization treatments highly influences the PC in 2015 ($F = 28.480^{**}$) and 2016 ($F = 18.470^{**}$) and significant in 2017 ($F = 3.802^{**}$). On average for all fertilizer variants in three-years study, the highest PC (12.136%) was obtained on the fertilizer variant T1. Based on the analysis of variance in three-year study, it can be concluded that the influence of growing seasons on PC was highly significant ($F = 21.304^{**}$). Different fertilization variants in study, highly influenced the PC of the grain ($F = 8.909^{**}$), Table 8.

Correlation analysis of the studied oat traits

Correlation coefficients based on all traits tested during 2014, 2015, and 2016 had positive and negative values in Table 9.

Positive correlation coefficients, during 2015 (Table 9), were found between GY with the PH ($r=0.827^{**}$), PL ($r=0.754^{**}$) and NGP ($r=0.615^{**}$), between PH with PL ($r=0.736^{**}$) and the NGP ($r=0.709^{**}$) and between the PL and NGP ($r=0.719^{**}$).

Highly significant negative dependencies were found between PC with GY ($r=-0.766^{**}$) and PH ($r=-0.677^{**}$) and significant were found between PC with PL ($r=-0.496^{*}$) and NGP ($r=-0.495^{*}$).

Highly significant and positive correlation coefficients, during 2016 in Table 9, were found between GY with PH ($r=0.805^{**}$), PL ($r=0.811^{**}$) and NGP ($r=0.719^{**}$), between PH with PL ($r=0.743^{**}$) and NGP (r=0.771**) and between PL and NGP (r=0.552**). Highly significant and negative dependencies were found between PC and PH (r=-0.807**), PL (r=-0.624**) and NGP (r = -0.761**) and significant with GY (r=-0.773*).

During 2017, highly significant positive correlation coefficients were found between GY with PH (r=0.806**) and NGP (r=0.734**). A high and positive dependence was found between PH and NBP (r=0.802**) and between PL and NGP (r=0.608**).

Significant and positive dependence was determined between GY and PL (r=0.430*), then between TGW and NGP (r=0.403*), between HW with PH (r=0.492*) and NGP (r=0.406*) as well as between PH and PL (r=0.427*). Negative dependencies were found between PC and GY (r=-0.766**), PH (r=-0.677**), PL (r=-0.496*) and NGP (r=-0.495*) in Table 9.

Table 9. Correlations between the traits analysed in the study period

Traits	GY	TGW	HW	PH	PL	NGP	PC
2015							
GY	1.00	0.153	-0.236	0.827**	0.754**	0.615**	-0.766**
TGW		1.00	-0.192	0.045	-0.075	0.104	0.016
HW			1.00	-0.312	-0.175	-0.150	0.066
PH				1.00	0.736**	0.709**	-0.677**
LP					1.00	0.719**	-0.496*
NGP						1.00	-0.495*
PC							1.00
2016							
GY	1.00	-0.041	-0.206	0.805**	0.811**	0.719**	-0.773*
TGW		1.00	0.121	-0.109	0.038	-0.114	0.021
HW			1.00	-0.213	-0.312	0.193	0.001
PH				1.00	0.743**	0.771**	-0.807**
LP					1.00	0.552**	-0.624**
NGP						1.00	-0.761**
PC							1.00
2017							
GY	1.00	0.169	0.269	0.806**	0.430*	0.734**	-0.557**
TGW		1.00	0.291	0.348	0.238	0.403*	-0.317
HW			1.00	0.492*	0.306	0.406*	-0.438*
PH				1.00	0.427*	0.802**	-0.399*
LP					1.00	0.608**	-0.374
NGP						1.00	-0.500*
PC							1.00
2015-2017							
GY	1.00	0.201	0.194	0.823**	0.721**	0.701**	-0.494**
TGW		1.00	0.456**	0.224	0.281*	0.202	0.139
HW			1.00	0.176	0.331**	0.245*	0.368**
PH				1.00	0.670**	0.759**	-0.459**
LP					1.00	0.641**	-0.225
NGP						1.00	-0.428**
PC							1.00

[1] GY-Grain yield (t ha^{-1}), TGW-1000 grain weight (g), HW-Hectolitre weight (kg hl^{-1}), PH-Plant height (cm), PL-Panicle length (cm), NGP-Number of grains (panicle), PC-Protein content (%);

[2] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01;

Over a three-year study period (2015-2017), highly significant positive correlation coefficients were found between GY with the PH, PL and NGP, then between the HW with the TGW, PL and PC and between the PH with the PL and NGP in Table 9.

The correlation coefficients in different fertilizer variants based on all the traits tested had positive and negative values in Table 10.

Table 10. Correlation coefficients for the traits analysed across treatments

Traits	GY	TGW	HW	PH	PL	NGP	PC
T1-control							
GY	1.00	0.479	0.442	0.505	0.214	0.240	-0.464
TGW		1.00	0.878**	0.219	0.164	-0.020	0.852**
HW			1.00	0.328	0.274	0.090	0.914**
PH				1.00	0.563*	0.681**	0.204
LP					1.00	0.574*	0.143
NGP						1.00	0.021
PC							1.00
T2-N							
GY	1.00	0.188	0.605*	0.442	0.418	0.506	-0.461
TGW		1.00	0.653**	0.223	0.335	0.020	0.552*
HW			1.00	0.405	0.542*	0.308	0.676**
PH				1.00	0.324	0.506	0.014
LP					1.00	0.315	0.648**
NGP						1.00	-0.083
PC							1.00
T3-NPK							
GY	1.00	-0.024	-0.031	0.544*	0.371	0.168	-0.210
TGW		1.00	0.243	0.175	0.180	0.285	0.014
HW			1.00	0.422	0.257	0.307	0.545*
PH				1.00	0.189	0.453	0.566*
LP					1.00	0.353	0.314
NGP						1.00	0.480
PC							1.00
T4-NPK in combination with lime							
GY	1.00	-0.037	0.481	0.393	0.718**	0.529*	-0.187
TGW		1.00	-0.020	0.653**	0.234	-0.068	0.365
HW			1.00	0.408	0.528*	0.753**	0.323
PH				1.00	0.588*	0.408	0.667**
LP					1.00	0.518*	0.434
NGP						1.00	0.372
PC							1.00
T5-NPK in combination with lime and manure							
GY	1.00	0.273	0.749**	0.452	0.594*	0.588*	-0.358
TGW		1.00	0.526*	0.463	0.613*	0.527*	0.335
HW			1.00	0.592*	0.704**	0.773**	0.358
PH				1.00	0.415	0.526*	0.383
LP					1.00	0.500	0.329
NGP						1.00	0.287
PC							1.00

[1] GY-Grain yield (t ha^{-1}), TGW-1000 grain weight (g), HW-Hectolitre weight (kg hl^{-1}), PH-Plant height (cm), PL-Panicle length (cm), NGP-Number of grains (panicle), PC-Protein content (%);

[2] T1-control, T2- N_{80}, T3-$N_{120}P_{80}K_{80}$, T4-$N_{120}P_{80}K_{80}$ + 5 t ha^{-1} lime and T5-$N_{120}P_{80}K_{80}$ + 30 t ha^{-1} manure + 5 t ha^{-1} lime

[3] Within years and treatments, the values in each column followed by a different letter are significantly different; *, ** - significant at 0.05 and 0.01;

Highly significant and positive correlation coefficients, in the variant without fertilization (T1), were found between TGW and HW (r=0.878**), TGW and PC (r=0.852**), HW and PC (r=0.914**) and between the PH and NGP (r=0.681**). Significant and positive dependencies were found between PH and PL (r=0.563*) and between PL and NGP (r=0.574*) in Table 10.

In the nitrogen-only fertilization variant (T2), highly significant positive correlation coefficients were found between TGW and HW (r=0.653**), HW and PC (r=0.676**), and between PL and PC (r=0.648**). Significant and positive dependence was found between TGW and PC (r=0.552*) and between HW and PL (r=0.542*) in Table 10.

Significant and positive correlation coefficients, in the fertilizer variant with NPK (T3), were found between GY and PH (r=0.544*) and between PC and HW (r=0.545*) and PC and PH (r=0.566*). A negative correlation was found between the GY of oats and TGW (r=-0.024) and the GY and HW (r=-0.031) in Table 10.

In the NPK and lime variant (T4), highly significant and positive correlation coefficients were found between GY and PL (r=0.718**), TGW and PH (r=0.653**), HW and NGP (r=0.753**), as well as between PC and PH (r=0.667**). Significant and positive relationships were found between GY and NGP (r=0.529*), HW and PL (r=0.528*), PH and PL (r=0.588*), and between the PL and NGP (r=0.518*). A negative dependence was found between the GY of oats and TGW (r=-0.037), as well as between the TGW and HW (r=-0.020) in Table 10.

In the fertilizer variant with NPK, lime and manure (T5), highly significant positive correlation coefficients were found between HW with the GY (r=0.749**), PL (r=0.704**) and NGP (r=0.773**). Significant and positive dependence was found between GY with the PL (r=0.594*) and NGP (r=0.588*) and between TGW and HW (r=0.526*), TGW and PL (r=0.613*) and TGW and NGP (r=0.588*). Also, a positive and significant dependence was found between the PH and HW (r=0.592*) and the PH and NGP (r=0.526*) in Table 10.

Discussion

Grain yield

Oats, among the small grains, is considered as are the plant species more tolerant to low soil pH values and high content of mobile Al compared to wheat (Đekić *et al.*, 2018; Rajičić *et al.*, 2019), as well as certain triticale genotypes (Đekić *et al.*, 2014; Terzić *et al.*, 2018; Rajičić *et al.*, 2020). According to the authors Đekić *et al.* (2012), varieties of spring oats tested to low soil pH values show very good results. Based on the level of GY achieved, spring oat varieties are known to be the most tolerant, while according to the TGW and PC, the Vranac variety proved to be more adaptable.

All fertilizer variants tested achieved the highest average yield in 2016 and the lowest in 2017 (Tab. 2). According to the data of the Statistical office of the Republic of Serbia, the average GY of oats in 2015 was 2.7 t ha^{-1}, in 2016 3.0 t ha^{-1}, while in 2017 it amounted to 2.4 t ha^{-1} (stat.gov.rs, 2020), which is in agreement with our results. A significant increase in GY in the second year of testing compared to the first and third years was due to the favourable effect of environmental factors, i.e. temperature and precipitation, on the yield components. Compared to the perennial average, rainfall in the second year of testing was significantly higher in May, which, with favourable temperatures, led to the formation of more grains per panicle and thus to higher yields. Significant deviation of precipitation and temperature from the perennial average in the Republic of Serbia is becoming more pronounced (Đekić *et al.*, 2014; Popović *et al.*, 2019). Namely, the total rainfall is reflected on a perennial average but the distribution, especially in the critical stages of development, is significantly disrupted (Đekić *et al.*, 2018; Terzić *et al.*, 2018; Rajičić *et al.*, 2020).

Newly created high-yielding oat varieties have been found to be less responsive to temperature deviation than is the case with rainfall (Krishna *et al.*, 2014; Szatanik-Kloc *et al.*, 2019). Đekić *et al.* (2012), point out that intensive pre-harvest rainfall in 2006 led to crop lodging in case of Vranac and Lovcen cultivars, which reduced GY. Jelic *et al.* (2013), point out that the GY of oat grains varied significantly by years of research and amounted to 2.639 t ha^{-1} in 2008, while a much higher GY of 3.985 t ha^{-1} was established in 2010. Also, Dumlupinar *et al.* (2011), state that differences in GY between years occur due to environmental conditions. The same authors point out that statistically significantly higher GY was achieved on all fertilizer variants of the experiment compared to the non-fertilizer variant and that for all varieties the highest GY (4.35 t ha^{-1}) was obtained on the fertilization variant with 90 kg N ha^{-1}. Mut *et al.* (2017), examining different oat genotypes over a two-year study, report that yields range from 2.432 t ha^{-1} to 5.650 t ha^{-1}. Due to the rapid development of the root system, oats are more tolerant of spring drought than other spring cereals (Zielinski *et al.*, 2017).

By analysing the results obtained, we can conclude that there is a significant dependence of GY on the year of study (Tab. 2), which is in agreement with the results of Jelic *et al.* (2013). In addition to genotype, GY of spring oats is greatly influenced by the fertilization system, which is one of the key factors, which affects the yield formed and its quality (Khan *et al.*, 2014; Monjezi-Zadeh *et al.*, 2018), but it needs to be aligned with climate and soil conditions as well as the requirements of the variety (Tomple and Hwan, 2018; Dumlupinar *et al.*, 2019).

In Sumadija conditions, a very significant difference between the GY of oats and the year of the study has been found by Đekić *et al.* (2012). The research conducted by Jelic *et al.* (2013), in Western Serbia at the Rudno site indicate a significant influence of the growing season and a highly significant effect of fertilization on oat GY, which is explained by the high adaptability of the yield components to environmental conditions, especially in the third year of the study, which was characterized by favourable precipitation distribution. Genotype × environment interactions are responsible for most of the variation in GY in cereals and represent a significant possibility for increasing yield under certain agro-ecological conditions Dumlupinar *et al.* (2019).

Climate change has the potential to both positively and negatively affect the location, timing, and productivity of crop at local, national and global scales (Popović, 2015; Mihailović *et al.*, 2020). Environmental law as a whole, and in particular the section on climate change, presents a complex challenge in various professional and scientific fields. The right of its instruments should help and improve solutions for overcoming the negative consequences of the complex problem of contemporary civilization in the field of climate change (Jovanović and Mihailović, 2020).

1000 grain weight

The 1000 grain weight during the three-year study period was 28.54 g. The values obtained are slightly higher than the TGW found by Jelic *et al.* (2013) and Kaziu *et al.* (2019), and lower than the results obtained by Tomple and Hwan (2018) and Dumlupinar *et al.* (2019). For the Solomom oat variety, over a three-year study, the TGW ranged from 23 g to 25.7 g (Sots and Kustov, 2014). Mut *et al.* (2017), examining different oat genotypes, stated that the TGW ranged from 24.5 g to 41.3 g.

In Western Serbia, very significant differences between the TGW and the year of research have been found by Jelic *et al.* (2013), while highly significant differences in the conditions of Šumadija region have been found by Đekić *et al.* (2018). The same authors did not find any significant effect on the TGW between the tested nitrogen and phosphorus fertilization standards. Also, Jelic *et al.* (2013), Tomple and Hwan (2018) and Szatanik-Kloc *et al.* (2019), did not find a significant effect of nitrogen on the TGW, which is consistent with our research. However, Rajičić *et al.* (2020), point out that increased doses of nitrogen have a significant effect on reducing the TGW. Climatic conditions are especially important during grain loading, as lack of moisture and high temperature during this period influence the reduction of TGW (Dumlupinar *et al.*, 2019), as confirmed by the results of these studies.

Hectolitre weight

The average three-year value of HW was the highest for the variant with combined application of NPK fertilizers with lime and manure (43.70 kg hl^{-1}). The values obtained were slightly lower than the HW obtained by Jelic *et al.* (2013) and Đekić *et al.* (2018). A significant influence of the growing season on HW in oats is also established by Jelic *et al.* (2013). During a two-year study, Mut *et al.* (2017) have found that the HW of 25 oats genotypes tested ranged from 41.5 to 52.3 kg hl^{-1}. Many researchers have found a high dependence on different doses of nitrogen and phosphorus fertilizers, calcification and humification per HW (Jelic *et al.*, 2013). The research conducted by Đekić *et al.* (2014), Terzić *et al.* (2018) and Rajičić *et al.* (2020), indicate that there is no significant correlation between HW and different fertilizer variants.

Plant height

Plant height is a direct component of resistance to crop lodging and an indirect component of GY and is one of the more important agronomic traits in oat breeding. More favourable conditions in 2016 caused higher average PH compared to 2015 and 2017. Batalova *et al.* (2010), point out the significant influence of the variety on the PL of oat, which ranged from 102.4 cm to 133.5 cm. Examining 100 varieties of oats of world origin in Turkey, during a two-year study, Mut *et al.* (2016) conclude that the PH of oats ranges from 76.2 to 141.2 cm. A significantly higher value of PH of oats is found by Kaziu *et al.* (2019). They state that the PH of oats during the study ranged from 118.5 cm to 160.4 cm between different genotypes. During a two-year study and examining of 25 oat genotypes, Mut *et al.* (2017), have found that the PH ranged from 76.3 to 128.3 cm. Dumlupinar *et al.* (2019), have found significant variation in the PH of oats (from 46 cm to 112.7 cm).

Although a cultivar trait, PH is not constant but susceptible to some degree of variation, which depends on the environmental influence under which the plants develop during the wilting phase (Batalova *et al.*, 2010; Tomple and Hwan, 2018). The height of oat plants depends on genotype, agro-ecological conditions and agro-technical measures (Surje and De, 2014; Mut *et al.*, 2016; Dumlupinar *et al.*, 2019; Kaziu *et al.*, 2019). Significant influence of year and genotype on the PH of oats is obtained by Surje and De (2014), Mut *et al.* (2016) and Dumlupinar *et al.* (2019), while the significant influence of fertilization on PH is established by Mohr *et al.* (2012) and Tomple and Hwan (2018).

Panicle length

Panicle length in the studies conducted by Batalova *et al.* (2010) rand from 19.5 cm to 31.4 cm. Kaziu *et al.* (2019), state that the PL across different oat genotypes ranged from 26 cm to 37.8 cm during the study, which is higher than our research. Tomple and Hwan (2018), point out that the maximum PL in both years of study (2016, 2017) is found in the fertilizer variant with 50 kg N ha^{-1} (17.9 cm and 16.7 cm). The same authors find a high dependence of PL on growing seasons and different nitrogen fertilization variants. Significant dependence of oat PL on genotype, year and their interactions were established by Dumlupinar *et al.* (2019).

Number of grains per panicle

The number of grains per panicle is the product of the number of spikelet and fertilized flowers per spikelet. Oat spikelet consists of 2 to 4 flowers. In facultative lines, the NGP depends mainly on the characteristics of the genotype and the sowing time (Mahadevana *et al.*, 2016). The NGP for different oat genotypes ranges from 65 to 184 found by Dumlupinar *et al.* (2019), 94 to 159 found by Kaziu *et al.* (2019) and 95 to 174 per panicle for Batalova *et al.* (2010). Dumlupinar *et al.* (2019), cite a significant dependence of year, genotype, and their interaction on the NGP. After fertilization, which is highly dependent on environmental factors (temperature, humidity, light, etc.), germ is formed, then endosperm and finally, after a series of anatomic-morphological and biochemical changes in the crop, a grain is formed (Saccomanno *et al.*, 2017).

Protein content

The chemical composition of the grain is one of the criteria for evaluating the quality of oats. Compared to wheat and barley, oat grain has a higher fat and cellulose content and a lower content of carbohydrates (Sterna *et al.*, 2016). The chemical composition of the grain is controlled by the variety, climatic and soil conditions and cultivation technology. Proteins make up the bulk of organic nitrogen compounds in grains. Protein content of oats is very important, since proteins have great nutritional and biological value (Ahmad *et al.*, 2011; Devi *et al.*, 2019). One of the goals of oat breeding is the selection of genotypes with an increased share of essential amino acids, which play a significant role in human and animal nutrition (Jordanovska *et al.*, 2018).

The average 3-year values of PC of oat grains varied between the fertilization treatments tested and ranged from 9.967% (T5) to 12.136% (T1). Mut *et al.* (2017), in the examination of different oat genotypes, state that PC ranges from 11.1 to 14.3%. Panasiewicz *et al.* (2017), in the examination of different doses of nitrogen on PC in oat grains, have found that with increasing nitrogen dose, protein content increased. That is, the lowest PC is found for the variant without fertilization (11.13%), compared to the variant with 50 kg N ha^{-1} (11.8%), while the highest PC in the oat grain is found in the variant with 150 kg N ha^{-1} (14.5%). For different fertilization variants, Monjezi-Zadeh *et al.* (2018), have found that the PC of oat grains ranged from 10.38% to 11.72%. Examining the effect of calcification and humification on PC of oat grains Jelic *et al.* (2013) state that it ranged from 10.17% to 12.04%. Jordanovska *et al.* (2018), point out that the PC of different oat varieties ranged from 11.99% to 14.62%, which is significantly higher than our results. Jelic *et al.* (2013), by regular use of NPK fertilizers with an increased content of phosphorous nutrient and combined application of NPK, lime and manure, have established the wheat grain higher in PC than control.

The research conducted by Jelic *et al.* (2013), indicate a highly significant influence of the growing season and fertilization on the PC of oat grains, which is in agreement with our research. Also, Dumlupinar *et al.* (2011), highlight the significant impact of the growing season and cultivar on PC of oat grains. Panasiewicz *et al.* (2017), find that there is no significant relationship between PC in oat grains and applied doses of nitrogen, although with increasing nitrogen doses PC increases. Many authors have found a highly significant effect of mineral nutrition and liming on the chemical composition of oat grains, and especially on PC (Mut *et al.*, 2016; Panasiewicz *et al.*, 2017; Monjezi-Zadeh *et al.*, 2018; Jordanovska *et al.*, 2018).

Correlations between the analysed traits

A strong positive correlation between small GY and TGW has been found by many researchers (Krishna *et al.*, 2014; Terzic *et al.*, 2018), medium (Jelic *et al.*, 2013; Đekić *et al.*, 2014, Güngör *et al.*, 2017), while weak positive dependence has been identified by Vaisi and Golparvar, (2013). Positive and weak dependence of GY and TGW (r=0.35) was found by Dumlupinar *et al.* (2012). Kaziu *et al.* (2019), found a weak negative and significant relationship between oat GY and TGW (r=-0.29). Mut *et al.* (2017), found a highly significant and positive correlation between GY and TGW (r=0.25**). The duration of the grain filling period is significantly influenced by environmental factors, above all the high temperatures that shorten this period (Güngör *et al.*, 2017). Selection of early-flowering genotypes can influence the formation of more flowers and a longer grain filling period, i.e. the selection of higher yielding genotypes (Mut *et al.*, 2018).

Many researchers have found weak positive correlations between small grain yields and HW of different fertilizer variants (Terzic *et al.* 2018; Rajičić *et al.* 2019). A significant and negative correlation between the GY of oats and HW in the variant with 80 kg N ha^{-1} (r=-0.64*) and in the variant with NPK, lime and manure (r=-0.55*) has been established by Jelic *et al.* (2013). The same authors have found a highly significant positive correlation between GY and HW by humification (r=0.79**). Negative and significant dependencies of TGW and HW at different fertilization rates with nitrogen and phosphorus have been found by Đekić *et al.* (2014). Mut *et al.* (2017), over a two-year trial, have found a positive correlation between GY and HW (r=0.246).

Analysing the interdependence of GY and PH, Krishna *et al.* (2014) and Shah *et al.* (2015), state that their correlation is positive and, depending on the material examined, ranges from weak to strong. A highly significant positive correlation between GY and PH is found by Surje and De (2014). A positive and significant correlation between the GY and PH of oats is determined by Mut *et al.* (2016) and Dumlupinar *et al.* (2019). Contrary to these authors, a weak negative correlation between GY and PH of oats is found by Dumlupinar *et al.* (2012) (r=-0.28*), Güngör *et al.* (2017) (r=-0.38) and Kaziu *et al.* (2019) (r=-0.23). Based on the results of their research, Dumlupinar *et al.* (2019), conclude that, even if there is no direct correlation between PH and GY, a decrease in plant height may influence the increase in yield indirectly, by increasing the TGW or increasing the resistance to crop lodging.

Based on the results of the correlation coefficients, Dumlupinar *et al.* (2012), point out that the PH is significantly positively correlated with the NGP (r=0.281*), which is in agreement with our study. Positive correlations between PH of oats and PL (r=0.384) and TGW (r= 0.116), PL and NGP (r=0.586) are found by Krishna *et al.* (2014). A significant dependence of the PH of oats with the NGP ($r=0.188^{*}$), TGW ($r=0.188^{*}$) and GY ($r=0.155^{*}$) and highly significant between PH and PL is found by Dumlupinar *et al.* (2019). Significantly positive correlation between the NGP and the PH ($r=0.60^{*}$) and between the NGP and PL ($r=0.71^{*}$) in oats is obtained by Batalova *et al.* (2010). A highly significant dependence in oats between the NGP and PL ($r=0.57^{**}$), NGP and TGW ($r=-0.79^{**}$) and NGP and GY ($r=0.78^{*}$) is found by Kaziu *et al.* (2019).

Conclusions

The method proposed by the present study for the evaluation of the distribution of fertilizers on oats was practical and efficient. The influence of different fertilization variants of NPK with nutrition, calcification and humification on the GY and yield components of oats in different growing seasons is analysed in the paper. Grain yield and quality were the best in the 2016 growing season, due to the favourable rainfall distribution, which favourably affected the production of oats, while the worst quality was established in 2017. The obtained results show a high effect of combined application of NPK fertilizers with lime and manure on GY and some parameters of its quality. The highest average three-year GY of oats was found in the fertilizer variant with combined application of NPK, lime and manure (3.802 t ha^{-1}), and the lowest in the non-fertilizer variant (1.119 t ha^{-1}). The application of this treatment resulted in a significant increase in GY and in particular increased grain quality parameters, especially protein content. The impact of climatic factors on the yield components and quality of oat grains was highly significant. The highly significant effect of fertilization on GY, PC of the grain, PH, PL, and NBP were determined. Highly significant positive correlation coefficients between HW and GY, PL and NBP were found in the fertilizer variant with NPK, lime and manure.

The results of the study indicate the importance of calcification and humification on the yield and yield components of oats, thereby reducing soil acidity, increasing yield and improving quality, which favourably affects more profitable production of oats.

Authors' Contributions

All authors have participated in this research. VR has designed, supervised and written the paper; DG, MD and MG have participated in the experimentation and sample collection; VP, AM and VU have analysed the data obtained; VR, VP and DT have overseen the project and revised the manuscript. All authors have read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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