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Full Length Article

Yield and Nutritional Status of Different Maize Genotypes in Response to Rates and Splits of Mineral Fertilization

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Abstract

Efficient fertilizer management in maize production is based on supplying adequate amounts of nutrients for optimum economic yield, while minimizing losses to the environment. Exploiting genotypic differences in fertilizers use is required for achieving nutrient-use efficiency and higher yield. This two-year field study was designed to evaluate the influence of different fertilizer combinations on nitrogen (N), phosphorus (P) and potassium (K) uptake patterns, and yield in novel maize hybrids. Four divergent maize hybrids NS 4023, NS 6010, NS 6030 and NS 640 were grown under eight NPK combinations: 1: $P_{60}K_{60}$; 2: $P_{60}K_{60}$ + $N_{min\ spring}$; 3: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{min\ spring}$; 4: $P_{60}K_{60}$ + $N_{60spring}$; 5: $P_{60}K_{60}$ + $N_{100spring}$; 6: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{60spring}$ + Zn; 7: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{80spring}$ + Zn; 8: $P_{60}K_{60}$ + $N_{160spring}$ + Zn in both years of study. Different NPK combinations significantly improved NPK contents in leaves and grains along with substantial increase in 1000-grain weight, grain yield, grain protein contents and net returns of all tested hybrids; however, hybrids behaved differently in this regard. The highest N content in maize leaves was found in NS 4023 (2.39%), potassium in NS 6030 and NS 6010 (1.73%). Fertilizer combinations with N addition in autumn and spring + Zn, fertilization based on N correction in spring, showed positive effects on N content in grain and leaves; however P contents in leaves were not affected with fertilization systems. Moreover, P and K concentrations in leaves and grains decreased, which may be associated to better efficiency of maize hybrids. The highest yield was obtained with $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{60\ spring}$ + Zn followed by fertilizer combinations, $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{80\ spring}$ + Zn and $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{min\ spring}$. The highest net benefit of 2091.6 and 2043.9 $ ha^{-1} was obtained in treatments: $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{60\ spring}$ + Zn and $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{min\ spring}$. In conclusion, the amount and timings of nutrients application significantly affect the yield and could help in determination of genotype potential. Moreover, the treatment combination, $P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{60\ spring}$ + Zn harvested maximum maize yield along with highest net benefits and benefit: cost ratio. © 2020 Friends Science Publishers

Keywords: Maize hybrids; Fertilization; Nutritional Status; Grain Yield; Net income

Introduction

In Serbia, maize (*Zea mays* L.) is one of the most important cereal crops. The concept of fertilizer use efficiency in maize implies not only the maximum crop uptake but also the availability of the applied nutrients under variable climatic, and soil conditions (physical, chemical and biological) (Đalović *et al.* 2015). The three macroelements, nitrogen (N), phosphorus (P) and potassium (K) are essential for maize growth and grain development (Setiyono *et al*. 2010). Improving nutrient use efficiency, (biomass or grain production per unit of nutrient available in soil) is important for ensuring global food production, reducing fertilizer inputs and potential environmental risks (Gao *et al*. 2009).

The understanding of plant physiology (uptake and partitioning in different plants parts) could help in better nutrient homeostasis. The dry matter in maize grain is obtained by photosynthesis after silking (Lee and Tollenaar 2007), while during grain filling (45–65% N) is contributed by vegetative organs' N remobilization (Yue *et al*. 2018). For maize cultivation, the optimum rate of N fertilizers

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depends on many factors as genotype, agronomic and environmental conditions. The fertilizer application affects the maize yield by affecting the photosynthetic efficiency, leaf area duration and leaf area index. The response of maize yield to N availability is determined by vegetative storage capacity, root uptake, source to sink efficiency (vegetative to developing kernels) and strength of kernel sink (Huber *et al*. 1994). In a study, it was found that in maize the variation in N utilization at low N input was greater at before or after flowering compared to high N input (Gallais and Coque 2005). In new maize hybrids, there is high tolerance of low resource availability, which enable them to perform better under stress environments compared to old ones (Araus *et al*. 2008). In low and high input agriculture, growing of N-efficient genotypes is an important prerequisite for integrated nutrient management (Mi *et al.* 2007). One crucial technology used to accomplish high yield per hectare is the use of genotypes that have higher NUE. Phosphorus along with N is another vital mineral nutrient which influence the dry matter accumulation in plants. The genotypes of maize have variation in adaptibility to different soil types and P uptake and utilization efficiency. To maintain maximum rate of photosynthesis the adequate amount of P is important for plants (Marschner 2012). In plants, like N and P, the K is also a mobile element and exists as cationic form and influence the enzyme activities, osmosis balance, translocation of soluble metabolites and protein synthesis (Hawkesford *et al.* 2012). Ciampitti *et al.* (2013) reported that in K-deficient soil, crop yield and the efficiency of N and P is reduced.

One of the most important factor influencing the maize grain mineral composition is fertilizer application. Nutrient management is a complex process, however, improving the understanding of how, when and where to apply nutrients in maize helps to optimize fertilizer application rates and timings. In plants, the uptake of nutrients and their translocation and accumulation depends on the environmental factors and the genotypes (Sui *et al*. 2013). This study was conducted with the objective to know the interactive effects of fertilizers (N, P and K) and genotypes on maize yield along with N, P and K contents in leaves and grains which could be helpful in explaining the response of different genotypes to selected nutrient levels in order to improve production of maize.

Materials and Methods

Study site, soil treatments and experimental design

Field trials were conducted for two years at the Experimental Station of Institute of Field and Vegetable Crops, Novi Sad, Serbia. The soil was typical calcareous chernozem in nature. Before the experimentation, the soil samples were taken at soil depth of 30 cm with auger (end of March 2011) and soil analysis report showed that the total soil N was (0.26 g kg^{-1}), P_2O_5 (18.70 mg kg^{-1}) and K_2O (21.00 mg kg^{-1}). The weather data during the growing season of both years is given in Table 1.

Standard agronomic practices were followed for growing maize. The preceding crop for maize was winter wheat. Selected plots were plowed every October up to 27–30 cm depth and seedbed preparation was done before sowing with heavy duty cultivators (Multi-Tiller) to 15 cm depth in March. Four divergent maize hybrids (NS 4023, NS 640, NS 6010 and NS 6030) were sown under 8 treatment combinations as: 1: $P_{60}K_{60}$; 2: $P_{60}K_{60}$ + $N_{min\ spring}$; 3: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{min\ spring}$; 4: $P_{60}K_{60}$ + $N_{60spring}$; 5: $P_{60}K_{60}$ + $N_{100spring}$; 6: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{60spring}$ + Zn; 7: $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{80spring}$ + Zn; 8: $P_{60}K_{60}$ + $N_{160spring}$ + Zn in both years of study. Zn was applied as zinc sulfate ($ZnSO_4$) in the amount of 1.0 kg ha^{-1} with foliar spraying, in the fourth and sixth week after sowing. The crop was sown on 10 April 2011 and 18 April 2012 using a Wintersteiger AG pneumatic precision seed drill to a depth of 5 cm. The plot dimensions were 5 × 2.8 m, having intra-row spacing of 22 cm and row spacing of 70 cm. In both years weed control was carried out by conventional chemical methods.

Measurements

Plant tissue analyses included concentration of N, P and K in leaves and grain. Leaf samples (25 leaves) were taken under the cob in the silking stage (the second half of July). After maize harvest from each elementary plot cobs were taken for grain chemical analysis. Samples of the plant material (leaves and grain) were prepared and milled in a mill for plant material grinding. Using AOAC Official method 972.43:2000, the total N was determined. Using ICP-AES the P and K were determined. Varian Vista-PRO Simultaneous ICP-AES, with axially mounted plasma was used for these measurements. The 1000-grain weight was evaluated by counting and weighting of 4 × 250 of unbroken maize kernels. The two center rows were used to collect yield data following Wasaya *et al.* (2017) and the two adjacent rows were used for plant sampling. Protein content was estimated as the total nitrogen by the Kjeldahl method multiplied by 6.25 (AOAC 2017).

Economic analysis

Economic analysis was performed to investigate the economic feasibility of treatments (fertilizer rates). Economic analysis was done using the prevailing market prices for all inputs used at planting and for outputs at the time the crop was harvested. Furthermore net income was calculated by subtracting total cost from gross income, and benefit cost ratio (BCR) was determined as ratio of gross income to total cost (Wasaya *et al.* 2018).

Data analysis

For the purpose of data analysis, statistical testing

Table 1: Total monthly precipitation and mean air-temperatures at the experimental station during 2012 and 2013

Years	Monthly precipitation (mm)							Monthly mean air-temperatures (°C)							
	Apr	May	Jun	Jul	Aug	Sep	Total	Apr	May	Jun	Jul	Aug	Sep	Mean
2011	22.8	63.0	36.9	61.5	1.5	25.4	174.2	13.2	16.8	20.9	22.1	23.0	20.4	19.4
2012	82.8	52.2	27.5	47.7	3.5	13.1	226.8	13.0	17.5	23.0	25.2	24.6	19.8	20.5
*1961-90	47	57	83	61	55	36	339	11.4	16.6	19.6	21.1	20.6	16.9	17.7

*Average of 1961–1990 (SHS 2012, 2013)

combined the results of the individual years of research. The basic model used for data analyses was divided subplots (Gomez and Gomez 1984). The effects of the main factors (year, fertilization systems and hybrids) were tested, as well as mutual interactions of the first and the second order. The plan involved calculating conferred subplots three experimental error which is done by testing the statistical significance of effects in the model. The mathematical model of the plan is divided subplots:

$$y_{ijkl} = \mu + \rho_i + \alpha_j + \varepsilon_{ij} + \beta_k + (\alpha\beta)_{jk} + \delta_{ijk} + \gamma_l + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + \xi_{ijkl}$$

y_{ijkl} - the value of the analyzed capacity; μ - general mean; ρ_i - The effect of the *i*-th repetition α_i (*i* = 1,...,*r*), β_k (*k* = 1,..., *b*) and γ_l (*l* = 1,...,*c*) the main effects of the factors, fertilization systems and hybrids; $(\alpha\beta)_{jk}$, $(\alpha\gamma)_{jl}$, $(\beta\gamma)_{kl}$ and $(\alpha\beta\gamma)_{jkl}$ the interaction of the first and second order; ε_{ij}, δ_{ijk} and ξ_{ijkl} the experimental errors with the assumptions about their distribution: $\varepsilon_{ij} : N\left(0, \sigma_a^2\right)$; $\delta_{ijk} : N\left(0, \sigma_1^2\right)$ and $\xi_{ijkl} : N\left(0, \sigma_2^2\right)$. Statistical analysis of divided plot model was carried out by using a mixed linear model, where they are treated as fixed main effects of the factors and their interactions and the repetition with experimental error treated as random effects. The differences between the levels of factors were tested by using *Tukey*-test with correction of the errors of the Type I (Hochberg and Tamhane 2011) (StatSoft Inc, Tulsa, OK, USA).

Results

Maize leaf and grain mineral contents (N, P and K) and grain yield

Different fertilizer combinations and maize hybrids had significant effect on leaf N, P and K concentartions of maize except the non-significant effect of fertilizer combinations on leaf K and hybrids on leaf P (Table 2). Years and interaction betweeen years and fertilizer combinations had significant effect only on leaf N of maize (Table 2). Interaction between years and hybrids had significant effect only on leaf N and K concentrations. Two-way interaction among fertilizer combinations and hybrids and three-way interaction among years, fertilizers and hybrids had non-significant effect on leaf NPK concentrations (Table 2).

Table 2: Influence of fertilizer application on leaf nitrogen, phosphorus and potassium concentrations in different maize hybrids

	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Years (A)			
2011	2.35 ± 0.3^{NS}	0.22 ± 0.02 b	1.11 ± 0.03 b
2012	2.31 ± 0.2	0.23 ± 0.01 a	2.23 ± 0.16 a
Treatments (B)			
$P_{60}K_{60}$	1.91 ± 0.1 d	0.19 ± 0.02 d	1.63 ± 0.60 b
$P_{60}K_{60}$+ $N_{min\ spring}$	2.38 ± 0.1 b	0.22 ± 0.01 bc	1.74 ± 0.65 a
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{min\ spring}$	2.57 ± 0.1 a	0.24 ± 0.01 a	1.69 ± 0.63 ab
$P_{60}K_{60}$ + $N_{60\ spring}$	2.04 ± 0.1 cd	0.20 ± 0.01 d	1.69 ± 0.61 ab
$P_{60}K_{60}$ + $N_{100\ spring}$	2.45 ± 0.1 ab	0.23 ± 0.01 ab	1.63 ± 0.58 b
$P_{60}K_{60}$+$N_{40\ autumn}$+$N_{60\ spring}$+Zn	2.58 ± 0.1 a	0.24 ± 0.01 a	1.62 ± 0.56 b
$P_{60}K_{60}$+$N_{40\ autumn}$+$N_{80\ spring}$+Zn	2.58 ± 0.1 a	0.24 ± 0.01 a	1.67 ± 0.60 ab
$P_{60}K_{60}$ + $N_{160\ spring}$ + Zn	2.14 ± 0.3 c	0.21 ± 0.02 c	1.67 ± 0.63 ab
Hybrids (C)			
NS 4023	2.39 ± 0.3 a	0.22 ± 0.02^{NS}	1.61 ± 0.50 b
NS 640	2.29 ± 0.3 b	0.22 ± 0.02^{NS}	1.60 ± 0.50 b
NS 6010	2.37 ± 0.3 a	0.22 ± 0.02^{NS}	1.73 ± 0.66 a
NS 6030	2.27 ± 0.2 b	0.22 ± 0.02^{NS}	1.73 ± 0.65 a
ANOVA			
Year (A)	ns	*	**
Treatment (B)	**	**	*
Hybrid (C)	**	ns	**
A × B	**	**	ns
A × C	ns	**	**
B × C	ns	ns	ns
A × B × C	ns	ns	ns

Means sharing the same letter, for a parameter and variable, don't differ significantly at $P \leq 0.05$
* = significant at $P < 0.05$; ** = significant at $P < 0.01$; ns = non-significant; ANOVA = analysis of variance

Analysis of variance showed a significant effect of treatments ($P < 0.05$), and highly significant effect of hybrid ($P < 0.01$) for maize grain N concentrations. The treatment and year (A × B) and year × hybrid (A × C) also showed a highly significant effect ($P < 0.01$). A statistically significant difference was observed between years for grain N concentrations but not for P and K (Table 3). Grain yield was also statistically significantly affected by the year. The higher grain yield was obtained in 2012 than in 2011. In 2012, favourable climatic conditions might have resulted in more grain yield. Among fertilizer combinations, $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{min\ spring}$, $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{60spring}$ + Zn and $P_{60}K_{60}$ + $N_{40autumn}$ + $N_{80spring}$ + Zn had higher yield while control ($P_{60}K_{60}$) observed the minimum yield. Likewise maize hybrid NS 6010 out yielded the other hybrids and NS 4023 was at the bottom in this regard (Table 3). Analysis of variance for TGW revealed a statistically significant effect of year (A) ($P < 0.05$) and a statistically significant effect

Table 5: Correlation between leaf N, P and K contents and maize grain yield and correlation between grain N, P and K content and maize grain yield

	Yield		N in leaf		P in leaf		K in leaf	
	2011	2012	2011	2012	2011	2012	2011	2012
Yield								
N	0.670**	0.395*						
P	0.725**	0.513**	0.945**	0.792**				
K	-0.003^{NS}	0.362*	0.300^{NS}	-0.031^{NS}	0.174^{NS}	0.065^{NS}		
	Yield		N in grain		P in grain		K in grain	
	2011	2012	2011	2012	2011	2012	2011	2012
Yield								
N	0.686**	0.391*						
P	0.585**	-0.054^{NS}	0.576**	0.260^{NS}				
K	0.365*	-0.292^{NS}	0.371*	0.089^{NS}	0.797**	0.853**		

Means sharing the same letter, for a parameter and variable, don't differ significantly at $P \leq 0.05$

* = significant at $P < 0.05$; ** = significant at $P < 0.01$; ns = non-significant; ANOVA = analysis of variance

Table 6: Economic analysis of different NPK fertilizers application rates (two-year average)

Treatments	Gross income ($\$ ha^{-1}$)	Total Cost ($\$ ha^{-1}$)	Net Benefits ($\$ ha^{-1}$)	Benefit Cost Ratio
Fertilizer combinations				
$P_{60}K_{60}$	1576.3	491	1085.3	3.21
$P_{60}K_{60} + N_{\text{min spring}}$	2315.2	512	1803.2	4.52
$P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{min spring}}$	2566.4	522.5	2043.9	4.91
$P_{60}K_{60} + N_{\text{60 spring}}$	2307.2	512	1795.2	4.51
$P_{60}K_{60} + N_{\text{100 spring}}$	2443.7	526	1917.7	4.65
$P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{60 spring}}$ + Zn	2624.6	533	2091.6	4.92
$P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{80 spring}}$ + Zn	2565.0	540	2025.0	4.75
$P_{60}K_{60} + N_{\text{160 spring}}$ + Zn	2254.5	554	1700.5	4.07
Hybrids				
NS 4023	2187.7	1047.5	1140.2	2.09
NS 640	2366.8	1047.5	1319.3	2.26
NS 6010	2419.0	1047.5	1371.5	2.31
NS 6030	2353.0	1047.5	1305.5	2.25

for treatment (B) and hybrids (C) ($P < 0.01$). Testing for variance analysis also found a statistically significant interaction effect between years tested and hybrid (A × C) ($P < 0.05$) and a statistically significant interaction effect between year and treatment (A × B) ($P < 0.01$) (Table 4). The average protein content of maize kernels for all fertilizer variants and hybrids by years of research ranged from 7.7% in 2011 to 8.5 in 2012. Significantly, the lowest protein content was found for the dose of fertilizers of 60 kg ha^{-1} P and 60 kg ha^{-1} K (6.9%) in comparison to the other levels of this factor. Grain protein content was significantly affected by the year, hybrids, fertilization strategies and their interactions (Table 4). Mean comparison of the two year data revealed that higher protein content was recorded in 2012. These results could be obtained due to plant stress in August, 2011 when the rainfall was low (1.5 mm) (Table 1). Similarly, Fowler *et al*. (1990) also reported higher grain protein content due to limited water availability in soil. These results are related to the finding of Gallais *et al.* (2008), who reported that different application fertilizers and at different timing had significant effect on grain protein content and maize yield.

During year 2011, the N (r = 0.670**) and P (r = 0.725**) content in maize leaves had highly positive correlation with grain yield. Leaf N content had also highly significant correlation with P content (r = 0.945**). Potassium, although essential macro element in 2011 did not showed a significant relationship with yield, or with other macronutrients in maize leaves. In year 2011, grain yield had highly positive correlation with grain N and P contents, and positive with K content (r = 0.365*). It is interesting that for the extremely dry year 2012, grain yield showed no significant correlation with grain P and K content and these correlations were even slightly negative. During year 2011, grain N content had highly positive correlation with grain P (r = 0.576**), and positive with grain K contents (r = 0.371*) (Table 5).

The Economic benefit of fertilizer use is affected by fertilizer cost, grain prices and ultimately how maize responds to fertilizer application. The cost of each input is given in Table 6. The highest net benefit of 2091.6 and 2043.9 $ ha^{-1} was obtained in treatments: $P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{60 spring}}$ + Zn and $P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{min spring}}$. The present investigation revealed that treatment combination, $P_{60}K_{60} + N_{\text{40 autumn}} + N_{\text{60 spring}}$ + Zn gave the highest benefit (2091$ ha^{-1}) and cost ratio (4.92). The economic net benefit of 1371.5 $ ha^{-1} was achieved from maize genotype NS 6010 (Table 6).

Discussion

Understanding the effects by the application of

Table 3: Influence of fertilizer application on grain nitrogen, phosphorus and potassium in different maize hybrids

Years (A)	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Maize yield (t ha^{-1})
2011	1.22 ± 0.12 b	0.23 ± 0.01 b	0.26 ± 0.01 a	10.380 ± 1.82 a
2012	1.36 ± 0.18 a	0.25 ± 0.02 a	0.25 ± 0.02 a	7.140 ± 0.85 b
Treatment (B)				
$P_{60}K_{60}$	1.11 ± 0.08 d	0.24 ± 0.02 ab	0.26 ± 0.01 a	5.924 ± 0.63 d
$P_{60}K_{60}$ + $N_{min\ spring}$	1.27 ± 0.08 b	0.23 ± 0.02 b	0.25 ± 0.01 a	8.701 ± 1.55 c
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{min\ spring}$	1.42 ± 0.12 a	0.25 ± 0.02 ab	0.26 ± 0.02 a	9.645 ± 1.71 a
$P_{60}K_{60}$ + $N_{60\ spring}$	1.16 ± 0.09 cd	0.23 ± 0.02 b	0.25 ± 0.01 a	8.671 ± 1.49 c
$P_{60}K_{60}$ + $N_{100\ spring}$	1.35 ± 0.13 a	0.24 ± 0.02 ab	0.25 ± 0.02 a	9.184 ± 1.89 b
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{60\ spring}$ + Zn	1.41 ± 0.11 a	0.25 ± 0.02 a	0.26 ± 0.01 a	9.864 ± 2.38 a
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{80\ spring}$ + Zn	1.42 ± 0.14 a	0.24 ± 0.02 ab	0.26 ± 0.01 a	9.640 ± 2.81 a
$P_{60}K_{60}$ + $N_{160\ spring}$ + Zn	1.22 ± 0.21 bc	0.24 ± 0.02 ab	0.26 ± 0.02 a	8.473 ± 2.02 c
Hybrid (C)				
NS 4023	1.29 ± 0.16 b	0.24 ± 0.02 bc	0.26 ± 0.01 ab	8.222 ± 2.23 c
NS 640	1.32 ± 0.18 ab	0.25 ± 0.02 a	0.26 ± 0.01 a	8.895 ± 2.21 b
NS 6010	1.22 ± 0.13 c	0.23 ± 0.02 c	0.25 ± 0.02 c	9.091 ± 2.10 a
NS 6030	1.35 ± 0.18 a	0.24 ± 0.02 ab	0.25 ± 0.01 bc	8.843 ± 2.19 b
ANOVA				
Year (A)	*	ns	ns	**
Treatment (B)	**	*	ns	**
Hybrid (C)	**	ns	**	**
A × B	**	ns	ns	**
A × C	**	ns	**	ns
B × C	ns	ns	ns	ns
A × B × C	ns	ns	ns	*

Means sharing the same letter, for a parameter and variable, don't differ significantly at $P \leq 0.05$
* = significant at $P < 0.05$; ** = significant at $P < 0.01$; ns = non-significant; ANOVA = analysis of variance

Table 4: Influence of fertilizer application on 1000-grain weight and protein contents in different maize hybrids

Years (A)	1000-grain weight (g)	Protein content (%)
2011	369.0 ± 24.3 a	7.7 ± 0.8 b
2012	358.5 ± 23.8 b	8.5 ± 1.1 a
Treatment (B)		
$P_{60}K_{60}$	325.8 ± 12.3 d	6.9 ± 0.5 d
$P_{60}K_{60}$ + $N_{min\ spring}$	364.3 ± 16.3 b	7.9 ± 0.5 b
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{min\ spring}$	370.2 ± 20.8 b	8.9 ± 0.8 a
$P_{60}K_{60}$ + $N_{60\ spring}$	348.1 ± 14.1 c	7.2 ± 0.6 cd
$P_{60}K_{60}$ + $N_{100\ spring}$	361.4 ± 8.0 b	8.4 ± 0.8 a
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{60\ spring}$ + Zn	383.7 ± 23.1 a	8.8 ± 0.7 a
$P_{60}K_{60}$ + $N_{40\ autumn}$ + $N_{80\ spring}$ + Zn	386.9 ± 19.3 a	8.9 ± 0.9 a
$P_{60}K_{60}$ + $N_{160\ spring}$ + Zn	369.7 ± 15.9 b	7.6 ± 1.3 bc
Hybrid (C)		
NS 4023	349.2 ± 21.0 d	8.1 ± 1.0 b
NS 640	359.8 ± 22.3 c	8.2 ± 1.1 ab
NS 6010	379.0 ± 24.8 a	7.6 ± 0.8 c
NS 6030	367.0 ± 21.1 b	8.4 ± 1.1 a
ANOVA		
Year (A)	*	*
Treatment (B)	**	**
Hybrid (C)	**	**
A × B	**	**
A × C	*	**
B × C	ns	ns
A × B × C	ns	ns

Means sharing the same letter, for a parameter and variable, don't differ significantly at $P \leq 0.05$
* = significant at $P < 0.05$; ** = significant at $P < 0.01$; ns = non-significant; ANOVA = analysis of variance

feertilization in maize is fundamental to improve the fertilization recommendations of nutrients. The use of maize genotypes that are able to utilize nutrients efficiently is an important strategy in the management of plant nutritional status; it is of particular importance with regard to nitrogen (N), phosphorus (P) and potassium (K), due to their high requirement and influence on plant growth (Đalović *et al*. 2015). Strategies of split application and delaying the basal application affected nutrient uptake and nutrient concentration in maize. Varying N content was mainly affected by the applied fertilization systems. Crop response to N fertilization is generally very prompt, depending on the source of N, plant growing stage, rainfall and temperature (Qiang *et al*. 2019). The highest mineral contents were found where N was applied in autumn and in spring. Stay-green genotypes allow a longer photosynthetic period and also longer nutrient uptake after silking stage (Borrell *et al*. 2001). Previously studies have shown (Li *et al*. 2014) a positive correlation with the concentration of N in soil and root development. If N has favorable distribution over soil profile, then the root grows into the deeper soil layers, where higher N concentration could be is found. Available N in subsoil could originate from remaining N from preceding crop or depleted from autumn application. Hence, such root development could be beneficial to increase plants tolerance to summer drought (Šeremešić *et al*. 2013; Mi *et al*. 2019). Rozas *et al.* (2004) found that maize can recover 43–53% of total N fertilizer application at planting compared to 62–74% when applied at the V6 stage. Rasse *et al*. (1999) reported similar corn grain yields among N treatments that included a single pre-plant application of 202 kg N ha^{-1} and split N applications of 101 kg N ha^{-1} in sandy loam soils. In a study by Silva *et al*. (2005), the authors stated that the split and the time of application of nitrogenous inputs are alternatives for increasing productivity. Subedi and Ma (2005) also documented a significant role and contribution of ear-leaf N to dry matter and grain yield production in conventional corn hybrids.

Equivalent P doses were applied in our trial to compensate variation in soils and climate and to highlight the effects of different maize hybrids and N fertilization treatments (Noureen *et al.* 2019). In maize, the leaf growth and senescence are affected by phosphorus as the deficiency of P reduces the leaf surafce area and slows down the rate of leaf appearance (Colomb *et al.* 2000). To represent critical nutrient amount, a range of concentartion is required owing to variation in soil, other production environment and climate (Yin and Vyn 2004). Conversely, investigated soil is considered sufficiently supplied with P and K while fertilization was applied to return nutrients removed by maize grain. The P concentration in whole plant from seedling to 6th leaf stage and fully expanded leaf prior to tasseling is reported as: sufficient (0.25–0.50%), low (0.22–0.25%) and critical (0.22%) Marschner (2012). In leaves, the low P and K concentration could be associated with better distribution of both elements to the grain or their high NUE by new genotypes. Damon and Rengel (2007) indicate that genetic factors rather than a potassium dose applied as a fertilizer affect the K content of plants. The differences in adsorption of K among different plant species are attributed to variations in the root structure, such as root density, rooting depth and root hair length (Nieves-Cordones *et al*. 2014).

The K content in leaves of tested maize hybrids are in agreement with Epstein and Bloom (2005), who reported 3.0–4.0% K as sufficient at seedling stage, 2.0–3.0% at vegetative stage in uppermost mature leaf and 1.8–3.0% at tasseling stage in ear leaf. Similarly, the positive effect of N fertilizer application on grain N concentrations were reported in other studies with varying N applications (Osborne *et al*. 2004). In a study, it was found that application of nitrogen in two split improved the biological yield, grain N contents and stover maize yield (Singh *et al*. 1986). Likewise, in Midwestern United States, grain P concentrations (1.8–4.1 mg P g^{-1} DM) in maize grain were found with adequate P and varying level of N application (Osborne *et al.* 2004). In another study, the grain P (2.1–3.8 mg P g^{-1} DM) were reported with varying P application levels and adequate N by Mallarino (1996).

The analysis of variance of the maize grain yield achieved during the experiment showed highly significant differences between the treatments with NPK mineral fertilization. In each year, a significant increase of yield was observed in all the treatments when compared to the control. Significant differences were also observed between the treatments tested, which means that the NPK doses applied had significant effects on the maize yield quantity. In maize, the grain yield and grain quality are the results of interaction agronomic, genetic and environmental factors. However, genotype had large infuence on grain composition (Cook *et al.* 2012), the availability of moisture and temperature during the whole developmental phase, especially during physiological stage play role. In a study, Đalović *et al* (2015) reported that generaly hybrids differ in grain yield due to genetic factors and physiological performance as long root system with plenty of root hairs to absorb more nutrients (Qiao *et al.* 2019) and canopy to intercept more photosynthetic light. In a study, it was found that application of N at 150 kg ha^{-1} significantly increased the ear height (4.13%), leaf length and width (2.36 and 4.30%) respectively, and grain yield (9.09%) compared to control (no N application) (Bukan *et al*. 2009). Meira *et al*. (2009), with five combinations of N applied at sowing and at the V8 stage (0 + 120, 30 + 90, 60 + 60, 90 + 30 and 120 + 0 kg ha^{-1} of N), verified the maximum yield of corn grains with the combination 30 + 90 kg ha^{-1} of N. In another study, Silva *et al*. (2005) stated that the split and the time of application of nitrogenous inputs are alternatives for increasing productivity.

Maize growers need balanced crop nutrition to maximize its yield potential and get the most out of their fertilizer investment. High fertilizer costs, inaccessibility and/or limited availability and relatively low cereal grain prices are some of the major impediments to increased fertilizer use in the region. The economic benefit of fertilizer use is affected by fertilizer cost, grain prices and ultimately how maize responds to fertilizer application. It could be observed that different level of fertilizer has significant effect on the yield or outputs. The various cost of production of maize under different level varies due to different cost of fertilizer incurred on each treatment. Variable cost incurred in this experiment varies from one treatment to another. The results of this research can be used to make tentative recommendations, which can be refined through multi-location testing over a wider area. The use of fertilizers that contain individual nutrient is recommended in future researches to come up with the best composition of nutrients specific for maize production in the study area.

Conclusion

Rate and time of fertilizer application significantly affected the grain yield and grain mineral composition of maize and help in exploiting the genetic potential of genotypes. Timely fertilization can increase crop yield and nutrient use efficiency. This study highlights the importance of NPK application to improve grain yield and provides a promising fertilizer recommendation for minimizing fertilizer inputs and optimizing maize production. Future research is still suggested to evaluate relationships between ear-leaf nutrient concentrations and grain yield for a wider range of genotypes, and on different soil types.

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