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Application of organic fertilizers as supplement to improve the yield and content indicators of maize

Kiegészítő szerves trágyák alkalmazása a kukorica termésmennyiségének és minőségének javítása érdekében

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ABSTRACT

Chemical fertilizers have almost completely replaced organic fertilizers in Hungary. However, their combined use can have many advantages. The present study aimed to examine the effects of some organic amendments [manure (M), green manure (GM), stem residues (SR)] on the yield and grain content indicators of maize (P0023 hybrid), at equidistantly increasing N application rates. The experiment was conducted between 10. May 2023. and 19. October 2023. in the International Organic Nitrogen Long-term Fertilization Experiment (IOSDV) in Keszthely, Hungary. In addition to the unfertilized Control, 3 main treatments (NPK, NPK+M, NPK+GM+SR) were set, within which 5 equidistantly increasing N rates (N0-4 = 0-70-140-210-280 kg N/ha) were applied. According to the results, organic supplementation had a statistically detectable effect on the yield ($P<0.05$), cob weight ($P<0.05$), cob length ($P<0.05$), thousand grain weight ($P<0.05$) and crude protein ($P<0.05$), crude fiber ($P<0.05$), starch ($P<0.05$) and crude ash ($P<0.05$) content of maize. The effect of N was evident, both in the case of yield ($P<0.05$), cob weight ($P<0.05$), cob length ($P<0.05$) and thousand grain weight ($P<0.05$). Crude protein content has also increased with the increase of nitrogen doses, while crude fiber content followed an opposite trend. The effect of different crop-enhancers on the crude fat content of maize ($P=0.197$) could not be detected. The study results indicate that organic amendments can be used effectively to improve most quantitative and qualitative traits of maize and reduce the need for inorganic N fertilizers.

Keywords: nitrogen, inorganic fertilizer, manure, green manure, stem residue

ÖSSZEFOGLALÁS

A műtrágyák szinte teljesen felváltották a szervestrágyákat Magyarországon. Együttes alkalmazásuknak azonban számos előnye lehet. Jelen kutatás célja egyes szerves termésnövelő anyagok [istállótrágya (M), zöldtrágya (GM), szármaradványok (SR)] kukorica (P0023 hibrid) termésmennyiségére és termés beltartalmi mutatóira gyakorolt hatásainak a vizsgálata volt, ekvidisztánsan növekvő N adagok mellett. A kísérlet Keszthelyen (Magyarország) zajlott, a Nemzetközi Szerves- és Nitrogén Műtrágyázási Tartamkísérletben, 2023. Május 10. és 2023. Október 19. között. A kezeletlen kontroll (Control) mellett 3 fő kezelés került beállításra (NPK, NPK+M, NPK+GM+SR), melyeken belül 5 ekvidisztánsan növekvő N dózist (N0-4 = 0-70-140-210-280 kg N/ha) alkalmaztunk. Az eredmények alapján a szerves kiegészítők statisztikailag kimutatható hatással voltak a P0023 hibrid termésmennyiségére ($P<0{,}05$), cső tömegére ($P<0{,}05$), cső hosszára ($P<0{,}05$), ezerszemtömegére ($P<0{,}05$) a szem nyersfehérje- ($P<0{,}05$), nyersrost- ($P<0{,}05$), keményítő- ($P<0.05$) és nyershamu-tartalmára ($P<0{,}05$). A N kezelés hatása mind a termésmennyiség ($P<0{,}05$), mind a cső tömeg ($P<0{,}05$), cső hossz ($P<0{,}05$) és ezerszemtömeg ($P<0{,}05$) esetében megmutatkozott. A N dózis emelésével a nyersfehérje-tartalom nőtt, míg a nyersrost-tartalom fordított tendenciát mutatott. A különböző termésnövelő anyagok kukorica nyerszsír-tartalmára ($P=0{,}197$) gyakorolt hatása nem volt kimutatható. A kutatás eredményei rámutatnak, hogy a szerves kiegészítők sikeresen alkalmazhatóak a kukorica mennyiségi és minőségi mutatóinak javítására, továbbá a N műtrágyaszükséglet csökkentésére.

Kulcsszavak: nitrogén, műtrágya, istállótrágya, zöldtrágya, szármaradvány

INTRODUCTION

Maintaining and stabilizing high yields is one of the most important tasks of the Hungarian agricultural sector. Due to global climate change, the extremes of temperature and water supply became more frequent, as a result of which the yields of maize (*Zea mays* L.) became more fluctuating. Between 2010 and 2022, its average annual yields varied between 3.4 t/ha and 8.6 t/ha in Hungary (KSH, 2022a).

The reduced use of organic substances may also jeopardize its future productivity. In Hungary, the possibilities inherent in the use of organic fertilizers are becoming less and less exploited. According to the data of KSH (Hungarian Central Statistical Office), the organically fertilized area has decreased by about half between 2004 and 2022 (from 460,177 ha to 233,590 ha) (KSH, 2021; KSH, 2022b). The main reason for that may be the significant decrease in the number of livestock holdings and mixed holdings that occurred between 2010 and 2020 (Farkas et al., 2023). In addition, the practice of removing or burning crop residues can also lead to nutrient deficiencies (Rees et al., 1997).

Maize is mainly used for livestock feed (66%), human consumption (20%) and industrial purposes (10%) (Gül, 2012). In addition to the quantity of the crop, great attention must also be paid to the qualitative parameters. They both can be improved by the combination of inorganic and organic fertilization (Shah et al., 2023; Gezahegn, 2021).

The adequate amount of N affects the grain yield and quality of maize positively (Zhang et al., 1993). In contrast, unnecessarily high doses of inorganic N can increase N_2O emissions and NO_3^- accumulation in the groundwater (Ramu et al., 2012).

The use of organic amendments alongside inorganic fertilizers results in better soil structure, water holding capacity, cation exchange capacity (CEC), increased soil organic matter (SOM) content, biological activity and nutrient cycling (Saha et al., 2008). The macro- and micro-nutrient content of organic fertilizers is also beneficial for plant development, yield and the nutritional quality of the grains (Zhang et al., 2015; Panagea et al., 2022).

In addition to the previously described positive effects, legumes used as green manure can fix atmospheric nitrogen, thereby reducing the required amounts of inorganic nitrogen fertilizers (Helming et al., 2014). Non-legume green manure crops also contribute to reducing mineral N loss by absorption and transforming it into organic form.

The proper management of crop residues is also important to improve soil fertility and quality (Mirzaei et al., 2021). Some researchers suggest that at least 50-70% of the crop residues should be left on the stubble in order to avoid the harmful effects on soil (Graham et al., 2007).

Organic fertilizer supplementation is considered an effective technique to maintain the sustainability of crop ecosystems (Gentile et al., 2008).

The main aim of the research is to draw attention to the potential inherent in the organic fertilizer supplementation technology. Our experiment attempts to present the effects of manure, green manure and stem residues on the yield and content indicators of maize at equidistantly increasing nitrogen application rates.

MATERIALS AND METHODS

Experimental design

The properties of P0023 maize hybrid were examined between 10. May 2023. and 19. October 2023. It was sown with a row spacing of 75 cm and a plant density of 75,000 plants/ha.

The research was carried out in the International Organic Nitrogen Long-term Fertilization Experiment (IOSDV) in Keszthely, Hungary (46° 45′ N, 17° 14′ E, 115 m). IOSDV is a bifactorial long-term experiment with a strip plot design and three replications. It has a three-course crop rotation, which consists of maize, winter wheat and winter barley. The gross size of the plots is 48 m². The factors of the experiment are inorganic N fertilizer rates and different organic fertilizers (manure, green manure and stem residues), applied as supplements. Each plot receives uniformly 100 kg P_2O_5/ha and 100 kg K_2O/ha, while N is applied in 5 equidistantly increasing rates (N0=0 kg N/ha, N1=70 kg N/ha, N2=140 kg N/ha, N3=210 kg N/ha, N4=280 kg N/ha in the case of maize). The 4 main treatments were as follows: ”Control”, where no crop enhancer was applied, „NPK”, where only inorganic fertilizers were applied, „NPK+M”, where manure was applied once in the cop rotation, in a dose of 35 t/ha every three years before maize, and ”NPK+GM+SR”, where oil radish (*Raphanus sativus* var. *Oleiformis*) was used as green manure in addition to the straw/stem residues left by the previous crop. It was sown, then ploughed into the stubble of autumn barley once during the rotation. In the case of stem residues, an extra 10 kg N/t SR was also applied.

The soil texture in the experimental area is sandy loam, soil type is Ramann brown forest soil (Eutric Cambisol). Based on soil tests, the soil had a $pH_{(KCL)}$ of 7.28 and a nutrient content of 0.11% N, 82.66 mg AL-soluble P_2O_5/kg and 172.52 mg AL-soluble K_2O/kg.

Monitoring of weather elements

Meteorological parameters (daily minimum temperature, daily mean temperature, daily maximum temperature, precipitation) were monitored by a QLC-50 automatic climate station, which is operating at the Agrometeorological Research Station of the Hungarian University of Agricultural and Life Sciences (MATE) Georgikon Campus, Keszthely.

Physical characteristics of the cobs

Corn cob sampling was carried out on 19. October 2023. 15 cobs were collected from all treatments. The cobs were husked, then weighed using analytical scales. The length of the cobs was measured using standard tape measure.

Thousand Grain Weight (TGW)

The grains were placed on aluminium trays, then oven-dried at 70 °C for at least 48 hours (until constant weight) in a Memmert UF450 drying cabinet. Weight loss was registered every 12 hours. Over the last 12 hours, the weight was stabilized. After that, the samples were put in a desiccator in closed jars for an hour. Grain counting was carried out with a Contador Electronic Seed Counter. The weight of 1000 grains was measured using digital analytical scales. 5 replicates per treatment were included.

Grain content indicators

Non-destructive determination of the most important content indicators, like crude protein, crude fat, starch, crude fiber and crude ash was carried out, using a FOSS NIRS™ DS 2500F feed analyzer. The values measured at a current moisture content were uniformly converted to a moisture content of 14%, using the following formula:

$$\text{value of the content indicator at 14\% moisture content} = \frac{\text{measured value of the content indicator} \times 0.86}{[100 - \text{measured moisture content(\%)}]\ /\ 100}$$

Statistical analysis

In order to compare the treatments, one- and two-way analysis of variance (ANOVA) tests were performed in IBM SPSS Statistics (version 22.0). Tukey’s HSD post hoc tests (P<0.05) were also performed to identify the differences between the experimental groups.

RESULTS AND DISCUSSION

Weather attributes of the growing season

The water supply (Figure 1) was balanced throughout the experimental period. 375.5 mm of precipitation fell in total. The middle of May was rainy, which ensured proper conditions for initial development. The monthly mean temperature was 15.4 °C in May, 20.09 °C in June, 22.25 °C in July, 21.08 °C in August, 18.82 °C in September and 14.57 °C in October.

The rainy and relatively mild summer ensured good fertility, as it prevented pistils and pollens from drying out. There were only 13 days on which the daily maximum temperature exceeded 32 °C (6 days in July, 7 days in August), which is considered hazardous in all phenological stages of maize (Crafts-Bandner and Salvucci, 2002). In conclusion, the weather of the crop year was adequate for maize cultivation.

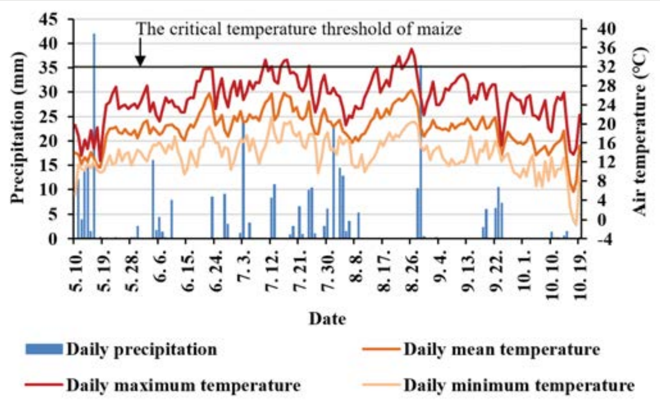


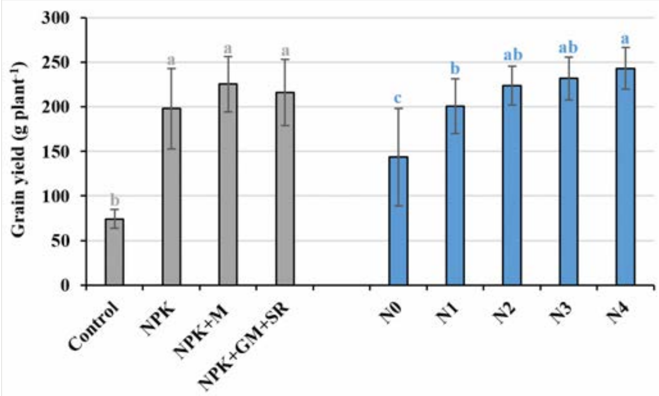
Figure 1. *In situ* observations of meteorological variables (daily precipitation, daily mean/maximum/minimum temperature) from the 2023 growing season (Keszthely, Hungary)

Grain yield

Based on the results of the two-way ANOVA, both fertilization treatment ($P<0.05$) and nitrogen treatment ($P<0.05$) had a significant impact on the grain yield of maize (Figure 2). The yield-enhancing effect of equidistantly increasing nitrogen application was also observed in the case of each treatment, but in the case of organically fertilized plots (especially in the case of NPK+M), the effect was less pronounced. At lower doses of N, the positive effect of organic substances prevailed.

The highest crop production (256.46±17.41 g/plant) was observed in the manured treatment, with a nitrogen dose of 280 kg N/ha. On average, the grain yield in NPK+M was 3.04 times higher than in Control, 1.14 times higher than in NPK and 1.04 times higher than in NPK+GM+SR treatments. The Tukey's HSD test also indicated that NPK+M could produce significantly higher ($P<0.05$) grain yield than the treatment where only NPK was applied. Almost similar results were reported by Shuyan et al. (2022). They concluded that cow manure compost (with an application depth of 20 cm, a dose of 24 t/ha, along with 0.6 t/ha mineral fertilizer) can increase the grain yield of maize by 6 to 28.4%, compared to the Control, treated only with mineral fertilizers.

Between NPK and NPK+GM+SR ($P=0.217$) and between NPK+M and NPK+GM+SR ($P=0.746$), no significant differences could be observed.



Different letters above the error bars indicate statistically significant differences at the $P<0.05$ level

Figure 2. The average grain yield (mean + SD) of P0023 maize hybrid depending on the variants of organic amendments (M = manure, GM = green manure, SR = stem residues) and nitrogen treatments (N0-4 = 0-70-140-210-280 kg N/ha)

Cob characteristics

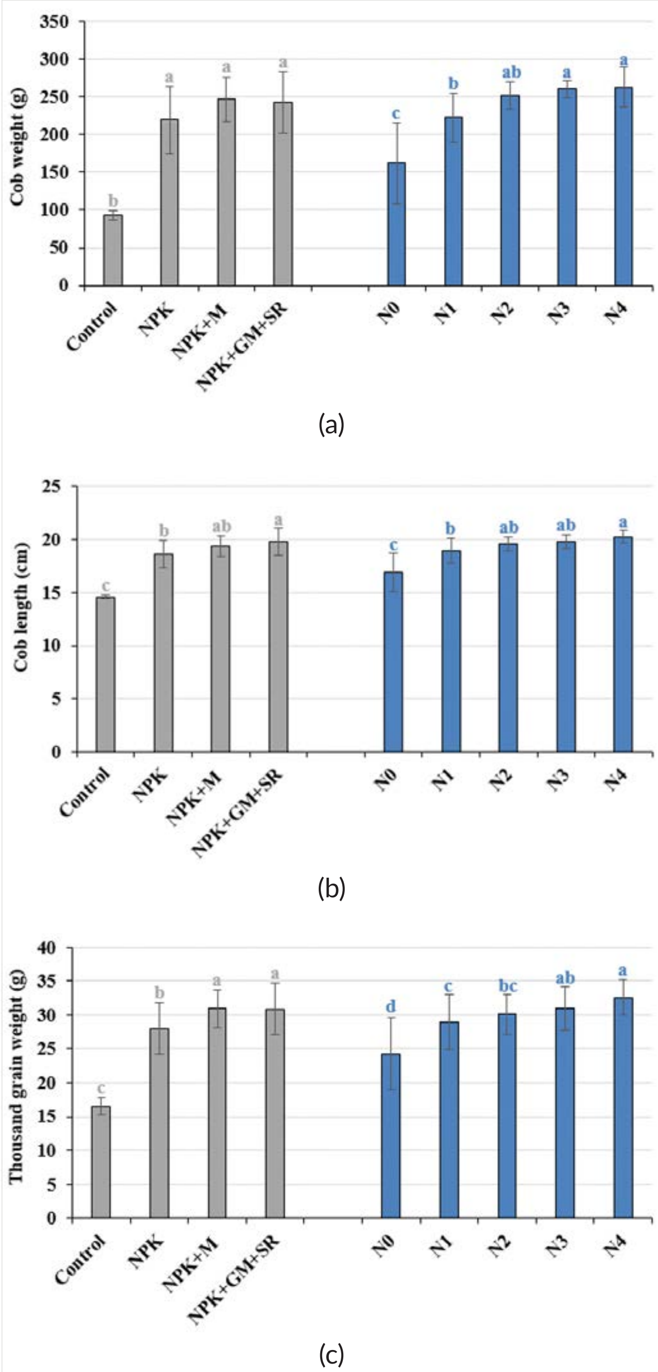
The positive effects of organic amendments were also reflected in cob weights (Figure 3a), cob lengths (Figure 3b) and thousand-grain weights (Figure 3c). The two-way ANOVA indicated that the treatments where organic substances were applied produced heavier and longer cobs than the others, where no, or only inorganic fertilizers were applied.

In the case of the unfertilized Control, all yield indicators differed significantly ($P<0.05$ in all cases) from the fertilized treatments.

Both fertilization treatment ($P<0.05$) and N treatment ($P<0.05$) had a significant effect on the cob weight (Figure 3a) of P0023 maize hybrid, but their interaction ($P=0.8$) could not be detected. An increasing trend parallel to the increase in N dose was observed. Based on Tukey's HSD test, cob weights in NPK+M and NPK+GM+SR differed significantly from Control (*P*<0.05, *P*<0.05) and NPK (*P*<0.05, *P*<0.05) treatments, but there was no significant difference between the two of them (*P*=0.951). On average, the cobs in NPK+M were 2.64 times heavier than in Control, 1.12 times heavier than in NPK and 1.02 times heavier than in NPK+GM+SR.

Cob lengths (Figure 3b) were also affected by fertilization treatment (*P*<0.05) and N treatment (*P*<0.05), but their interaction (*P*=0.061) could not be detected. The effect of N was not as pronounced as in the other results. The Tukey's HSD test has shown significant differences between NPK and NPK+M treatments (*P*<0.05) and NPK and NPK+GM+SR treatments (*P*<0.05). Between NPK+M and NPK+GM+SR, no significant difference was observed (*P*=0.413). On average, the longest cobs could be measured in the NPK+GM+SR treatment (19.73±1.22 cm). These cobs were 5.18 cm longer than in Control, 1.13 cm longer than in NPK and 0.4 cm longer than in NPK+M. Shah et al. (2023) also reported that organic fertilizers have a significant effect on cob characteristics. In their study, the highest cob length (21.93-22.47 cm), grain rows per cob (19.7-20.47) and number of grains per cob (835.3-875.9) values were achieved by using pollutary manure, while the minimum values (14.27-15.13 cm, 13.27-14.37, 358.9-413.7) were measured by using soleley inorganic fertilizers.

TGW values (Figure 3c) show an almost similar pattern. Based on the results of the two-way ANOVA, both fertilization treatment (*P*<0.05) and N treatment (*P*<0.05) influenced the TGW of maize significantly. The Tukey's HSD test indicated significant differences between NPK and NPK+M (*P*<0.05) and NPK and NPK+GM+SR (*P*<0.05). In the case of TGW, no significant difference was observed between the two organically fertilized treatments (*P*=1). The highest value was 310.34±27.4 g in NPK+GM+SR, which was 145.01 g higher than in Control, 30.06 g higher than in NPK and only 1.17 g higher than in NPK+M. Munyabarenzi (2014) also concludes that the combination of mineral and organic fertilizers influences the grain yield and TGW of maize significantly (*P*<0.05). The reason for the increase in TGW was mainly due to the balanced and continuous supply of nutrients, which was provided by the organic substances (Cheema et al., 2010).



Different letters above the error bars indicate statistically significant differences at the *P*<0.05 level

Figure 3. Physical properties of the cobs of P0023 maize hybrid (mean + SD), depending on the variants of organic amendments (M = manure, GM = green manure, SR = stem residues) and nitrogen treatments (N0-4 = 0-70-140-210-280 kg N/ha)

Grain composition

Both fertilization treatment (*P*<0.05) and N treatment (*P*<0.05) had a significant effect on the crude protein content of maize (Table 1). In the case of crude protein, all fertilization treatments differed significantly (*P*<0.05 in all cases) from one another. The highest values were measured in the case of NPK+M.

Table 1. The grain content indicators of P0023 maize hybrid, when applying supplemental manure (M), green manure (GM) and stem residues (SR) in addition to inorganic fertilizers (NPK), at equidistantly increasing nitrogen application rates (N0-4 = 0-70-140-210-280 kg N/ha)

Treatment	Crude protein	Starch	Crude fat	Crude fiber	Crude ash
			Control		
Control	4.91 ± 0.22	64.18 ± 0.75	3.42 ± 0.05	2.36 ± 0.14	1.30 ± 0.1
			NPK		
N0PK	5.53 ± 0.5[c]	64.52 ± 0.55	3.45 ± 0.03	2.14 ± 0.11[a]	1.27 ± 0.05
N1PK	6.15 ± 0.69[bc]	64.85 ± 0.59	3.47 ± 0.03	2.1 ± 0.16[a]	1.26 ± 0.03
N2PK	7.2 ± 0.34[a]	64.52 ± 0.82	3.44 ± 0.07	1.97 ± 0.11[ab]	1.24 ± 0.03
N3PK	7.37 ± 0.36[a]	64.01 ± 0.49	3.46 ± 0.03	1.86 ± 0.13[b]	1.26 ± 0.03
N4PK	6.74 ± 0.53[ab]	64.27 ± 0.75	3.44 ± 0.05	1.84 ± 0.1[b]	1.24 ± 0.03
P-values of N treatment effect	<0.05	0.904	0.674	<0.05	0.152
			NPK+M		
N0PK+M	6.7 ± 0.33[b]	65.15 ± 0.45	3.46 ± 0.03	1.98 ± 0.12	1.25 ± 0.03
N1PK+M	7.18 ± 0.52[ab]	63.98 ± 0.47	3.43 ± 0.05	1.93 ± 0.1	1.28 ± 0.05
N2PK+M	7 ± 0.71[ab]	63.76 ± 0.66	3.42 ± 0.06	1.87 ± 0.12	1.27 ± 0.05
N3PK+M	7.52 ± 0.49[a]	63.85 ± 0.47	3.46 ± 0.02	1.92 ± 0.08	1.27 ± 0.04
N4PK+M	7.46 ± 0.38[a]	63.97 ± 0.22	3.47 ± 0.04	1.89 ± 0.14	1.28 ± 0.03
P-values of N treatment effect	<0.05	0.463	0.12	0.249	0.665
			NPK+GM+SR		
N0PK+GM+SR	5.45 ± 0.65[b]	64.56 ± 0.6	3.44 ± 0.03	2.1 ± 0.16[a]	1.25 ± 0.03[ab]
N1PK+GM+SR	6.96 ± 0.33[a]	64.11 ± 0.45	3.44 ± 0.03	1.97 ± 0.07[ab]	1.27 ± 0.03[ab]
N2PK+GM+SR	7.35 ± 0.18[a]	63.95 ± 0.43	3.48 ± 0.03	1.9 ± 0.06[b]	1.23 ± 0.02[b]
N3PK+GM+SR	7.19 ± 0.34[a]	64.32 ± 0.55	3.43 ± 0.05	1.85 ± 0.11[b]	1.25 ± 0.04[ab]
N4PK+GM+SR	7.41 ± 0.45[a]	64.26 ± 0.67	3.45 ± 0.05	2 ± 1.45[ab]	1.29 ± 0.04[a]
P-values of N treatment effect	<0.05	0.212	0.112	<0.05	<0.05
			P-values		
P-values of fertilization treatment effect	<0.05	<0.05	0.197	<0.05	<0.05

Different uppercase letters in the same column indicate distinct differences at the *P*<0.05 level

On average, the crude protein content of NPK+M was 1.04 times higher than in NPK+GM+SR, 1.09 times higher than in NPK and 1.46 times higher than in Control. Micskey (2012) reported greater differences: a crude protein content of 8.94% with a manure supplementation of 35 t/ha, while her solely minerally fertilized maize treatment reached only 7.36%. In general, the amount of crude protein increased in parallel with the increase of nitrogen dose.

Fertilization treatment ($P<0.05$) had a significant effect on starch content (Table 1), but nitrogen dose did not ($P=0.107$). According to Tukey's HSD test, there was a significant difference only between NPK and NPK+M ($P<0.05$).

Based on the data, crude fat content (Table 1) was neither affected by fertilization treatment ($P=0.219$) nor by N treatment ($P=0.949$).

The highest average crude fiber content (2.36±0.14%) (Table 1), which was significantly different ($P<0.05$) from all the other treatments, was measured in Control. There were no statistically detectable differences ($P=0.06$-0.897) between the other treatments. An opposite trend can be observed between crude protein and crude fiber contents: as nitrogen doses increased, crude protein contents increased as well, while crude fiber contents decreased. This phenomenon was also noticed by Almondares et al. (2009), who carried out a similar experiment on maize and grain sorghum.

In the case of crude ash content (Table 1), there was a significant difference only between Control and NPK ($P<0.05$) treatments. Nitrogen treatment did not affect this variable significantly ($P=0.211$).

CONCLUSIONS

The present study demonstrates that organic fertilizer supplementation improves most quantitative and qualitative traits of maize. N treatment determined all results, however the effect of inorganic N was less pronounced in NPK+M and NPK+GM+SR treatments, where organic amendments were also applied. It can be assumed that the prolonged decomposition of organic matter ensured continuous macro- and micro-nutrient supply, which helped to achieve higher yields even with lower levels of inorganic N. Therefore, the use of inorganic N fertilizers and the associated costs and environmental risks can be reduced by applying the appropriate type and amount of organic amendments.

The weather conditions of the 2023 growing season were favorable for the proper utilization of organic fertilizers. Since the beginning of the growing season was rainy, it can be assumed that the easily soluble NO_3^- was partially lost through leaching. However, the warm and humid conditions were favourable for the activity of microbial communities and the continuous decomposition of organic amendments.

The yield indicators of maize were examined under favourable environmental conditions, but in later years, considering the trends of climate change, different results may be measured. A dry vintage would probably modify the results to some extent. Hence, the examination of vintage effect on organic fertilizer supplementation is also recommended.

Further research should also be conducted to find the best site-specific combinations of inorganic and organic substances.

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