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Effects of organic amendments on yield determining properties and macronutrient content of maize

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Original article

Abstract

The use of organic fertilization is declining in Hungary due to the sharp fall of livestock stand since the middle of the 1980s. Most farmers are forced to use solely chemical crop enhancers. A bifactorial small plot experiment was carried out between 10 May 2023 and 19 October 2023 in Keszthely, in order to examine the effects of farmyard manure (M), green manure (GM) and stem residues (SR) on the nutrient uptake and nitrogen utilization efficiencies of maize at equidistantly increasing (0–70–140–210–280 kg N ha^{-1}) nitrogen doses. The relationship between some vegetative traits (dry biomass weight, Leaf Area Index (LAI)) and yield, furthermore leaf relative water content (RWC) was also examined. According to the results, organic fertilizer substitution significantly increased the N content both in whole plant and grain samples of NPK+M and NPK+GM+SR treatments, compared to the chemically fertilized control (NPK). In case of P and K only slight differences were observed. Whole plant K contents of NPK+M were significantly higher than in the other treatments (P = 0.045; P = 0,005), furthermore P contents in grain samples were significantly higher in NPK+M (P = 0.004) and NPK+GM+SR (P = 0.05) than in control. Harvest index (HI [%]) of NPK+M and NPK+GM+SR were 1.06 and 1.05 times higher than in NPK. Depending on the treatment, P0023 maize hybrid absorbed 58.7–74.64% of total N uptake in the grain ($HI_{N\%}$), and the utilization of 1 kg N fertilizer for the extra yield above the yield of the individual control was 0.39–1.38 kg (AREN). Significant positive correlations were observed between dry biomass weight and yield (NPK: r = 0.937, P = 0.019; NPK+M: r = 0.971, P = 0.006; NPK+GM+SR: r = 0.88, P = 0.049), furthermore LAI and yield (NPK: r = 0.9, P = 0.037; NPK+M: r = 0.983, P = 0.003; NPK+GM+SR: r = 0.784, P = 0.117). Highest RWC values – which may be related to better soil aggregate stability – were measured in NPK+GM+SR treatment, therefore there may be a great potential in this treatment among drought conditions. The effect of organic amendments is

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particularly noticeable with smaller nitrogen doses so they should be used to reduce inorganic fertilizer application and the resulting environmental risks.

Keywords: maize, farmyard and green manure, stem residues, nitrogen, fertilization

Introduction

Maize (*Zea mays* L.) takes a leading place among the main grain crops in the Hungarian agricultural production. According to the data of the Hungarian Central Statistical Office, in 2022, maize was sown on 983,000 hectares (URL1). It is widely used for both human and animal nutrition, industrial purposes, furthermore, its stem residue and cobs can also be used for heating, or as a source of soil nutrients (ANTAL et al., 2005). In case of maize, the optimal amount of macronutrients is 60–120 kg N ha^{-1}, 70–80 kg P_2O_5 ha^{-1} and 90–110 kg K_2O ha^{-1}, depending on soil properties, pre-crop, hybrid and vintage effect (SÁRVÁRI & KOVÁCS, 2017). Plant growth and development is directly affected by the availability of nutrients, from which nitrogen is one of the most important nutrients in metabolism (LAYARA et al., 2019). Yield is also determined to the greatest extent by N (NÉMETH, 2006; MOLNÁR, 2020). It affects dry matter production by influencing leaf area development, photosynthetic capacity, and consequently yield and grain content indicators (MUCHOW, 1998). As a consequence of N application rates above crop needs, adverse environmental effects, like soil acidification, N_2O emissions and NO^{3-} accumulation in the groundwater can occur. In addition to it, by using solely inorganic fertilizers, the nutritional needs of plants can only be satisfied on a shorter term (MIKÓ et al., 2008; RAMU et al., 2012). In the long run, regular application of organic fertilizers can also be inevitable. Due to the sharp fall of livestock stand since the middle of the 1980s, the organically fertilized area has shown a decreasing trend in Hungary. In addition to providing macro- and micronutrients (N, P, K, Mg, Ca, S, Mn), farmyard manure has many advantages on crop produce, as it improves the physical (soil structure, water retention capacity), chemical (meso- and micronutrients, enzymes, hormones) and biological (microbial activity) properties of soil (BOTIR et al., 2019; MALIESWARAPPA et al., 1999; HAYNES & NAIDU, 1998). According to some sources, organic fertilizers can significantly increase crop chlorophyll content, which enhances photosynthetic activity, water use efficiency and the accumulation of assimilates (YE at al., 2022; ZAITUNIGULI et al., 2021). Legumes used as green manure increase soluble nitrogen content of soil, due to biological fixation of atmospheric nitrogen, thus reducing the amount of inorganic N fertilizer required (URL2). Non-legume green manure crops are also advantageous as they reduce nutrient loss by absorption and transforming mineral N into organic form. Leaving the crop residue of the pre-crop on the plot has also many advantages. It decreases the risk of erosion and deflation, can provide nutrients, increases the soil organic matter content, water use efficiency, soil structural stability, soil expansion, and reduces soil bulk density, which all contribute to achieving higher yields (LI et al., 2019; REICHEL et al., 2018; SOON et al., 2012).

The main aim of the study was to analyze the effects of organic fertilizer substitution on plant nutrient uptake and utilization efficiencies, with particular regard to nitrogen. An other aim was to examine the relationship between the vegetative characteristics and the yield of maize.

Materials and methods

Characteristics of the field experiment

The research was carried out between 10 May 2023 and 19 October 2023 in Keszthely, Hungary (46° 45′ N, 17° 14′ E, 115 m), in the International Mineral and Organic Nitrogen Fertilization Trial (IOSDV), which is a bifactorial long-term experiment that has been running since 1983. In the experimental area, the soil texture is sandy loam and soil type is Eutric Cambisol whose humus content is 1.6–1.7%, total N is 0.12%, AL(P_2O_5) is 60–80 mg kg^{-1}, AL(K_2O) is 140–160 mg kg^{-1}, pH(KCl) is 6.8–7.0 on the average (CSITÁRI et al., 2021). The experiment has a strip-plot design and a three course cereal crop rotation which consists of maize, winter wheat and winter barley in this order. This paper only discusses data on maize. The area of the plots is 48 m^2. Ploughing, cultivation, applied hybrid (P0023) seeding rate (76,000 seeds ha^{-1}) and row spacing (75 cm) are the same for all plots. The two factors are organic amendments (control; farmyard manure; green manure + straw/stem residues) as main factor, and N rates (N_0; N_1; N_2; N_3; N_4), as sub-factor. In terms of fertilization, all experimental plots receive uniformly 100 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O while N is applied in 5 equidistantly increasing rates (0–70–140–210–280 kg ha^{-1}). The 3 main treatments, within which N doses were applied in 3 repetitions are as follows:

- NPK: only inorganic fertilizers (N, P, K) were applied;
- NPK+M: inorganic fertilizers (N, P, K) and farmyard manure (35 t ha^{-1}, 0.5% N, every 3 years before maize) were applied;
- NPK+GM+SR: inorganic fertilizers (N, P, K), oil radish (*Raphanus sativus* var. *Oleiformis*) as green manure and straw/stem residues of the pre-crop were applied.

Weather attributes of the experimental period

Daily mean temperature, daily maximum temperature and precipitation were monitored by a QLC-50 automatic device, which has been operating since 1996 at the Agrometeorological Research Station of MATE, Georgikon Campus, Keszthely (KOCSIS & ANDA, 2008). Based on the data, it was an optimal crop year for maize, both in terms of precipitation, distribution of rainy days and temperature. A total of 375.3 mm precipitation (92.5 mm in May, 51.7 mm in June, 88.2 mm in July, 106.8 mm in August, 32.3 mm in September, 3.8 mm in October) fell on 56 rainy days during the experimental period. Monthly mean air 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. A maximum temperature above 32 °C can be harmful to maize in each phenologycal phase (CRAFTS-BANDNER & SALVUCCI, 2002). This value was exceeded only on 11 days during the experimental crop year.

Plant sampling and preparation for harvest

5 whole aboveground plant samples were collected per plot, on 18th October 2023, just before harvest (BBCH 99). Fresh weight was registered on site, then the samples dried under greenhouse conditions, then oven dried at 40 °C, and weighed.

Starting from 28 September 2023, the moisture content of the grains of 12 cobs from random locations of the field was monitored every 3 days, using a FOSS NIRS DS 2500F feed analyzer in order to determine the most suitable time for harvest. Based on the data, the most appropriate time for harvest was 19 October 2023 (15.08% moisture content). Cob sampling (from 10 plants per plot) was carried out by hand, thus harvest losses were eliminated.

Estimation of the macronutrient (NPK) content of plant- and grain samples

Previously dried plant and grain samples were ground, using a Retsch SN 200 cutting mill and a Fritsch Analysette 3 Spartan Pulverisette 0.

Analysis of N

To determine N-contents an Elementar Vario Macro Cube CHN analyzer (Germany) was used. 100 mg of plant and grain samples (10–50 µm) were placed in tin containers (8×55 mm), then burned in the analyzer.

Analysis of P

Phosphorus contents were measured using the slightly modified method of SÁRDI (2016). 500 mg of plant and grain samples were treated individually with 10 mL HNO_3 (65% Merck), then digested for 1 hour in a Mars 6 iWave OneTouch microwave digestion system. The solutions were brought at 50 mL, then 10–10 mL from these stock solution was pipetted into 100 mL volumetric flasks. They were treated individually with 25 mL ammonium molybdovanadate reagent, then brought at 100 mL. P contents were analyzed on 410 nm, using a Thermo Scientific Genesys 10s UV-VIS spectrophotometer.

Analysis of K

Potassium contents were determined using the description of BARBES et al. (2014). Dried and ground samples were treated individually with 8 mL HNO_3 (65% Merck) and 10 mL H_2O_2 (30% Merck), then put in a Mars 6 iWave OneTouch microwave digestion system for 1 hour. After filtering the solutions, they were borught at 50 mL with distilled deionized water and analysed by an ICE 3000 Series Atomic Absorption Spectrophotometer.

Calculation of harvest index and indices of N use efficiency

Harvest index and the indices of N use efficiency were determined by the following formulas (DONALD & HAMBLIN, 1976; CRASWELL & GODWIN, 1984; HUGGINS & PAN, 1993):

$$\text{Harvest index [\%](HI)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

$$\text{N harvest index [\%]}(\text{HI}_{\text{N\%}}) = \frac{\text{N accumulated in grain}}{\text{N accumulated in total biomass}} \times 100$$

$$\text{N utilization efficiency (NUtE)} = \frac{\text{Grain yield [kg ha}^{-1}]}{\text{N absorbed at maturity [kg ha}^{-1}]}$$

$$\text{Agronomic efficiency (AE)} = \frac{\text{Grain yield of fertilized crop [kg ha}^{-1}] - \text{Grain yield of unfertilized crop [kg ha}^{-1}]}{\text{Quantity of N applied [kg ha}^{-1}]}$$

$$\text{Apparent recovery efficiency of N (AREN)} = \frac{\text{N uptake of fertilized crop [kg ha}^{-1}] - \text{N uptake of unfertilized crop [kg ha}^{-1}]}{\text{Quantity of N applied [kg ha}^{-1}]}$$

Depending on weather and soil attributes, the release of nutrients generally takes longer in case of organic amendments, than by inorganic fertilizers. Therefore, when calculating the indices (AE, AREN), the N content of organic amendments was not taken into account. These N sources were interpreted as part of the soil's (artificially elevated) nutrient supply capacity. During the calculations only inorganic fertilizer N was taken into account.

Determination of LAI

The maximum length and width of each leaf of 5 plants (BBCH 79) per plot was measured on 16 August 2023, using standard tape measure. To calculate LAI, leaf area (LA) was determined beforehand. For this reason the Montgomery equation was used, which is considered the most accurate in case of maize (HORVÁTH et al., 2013):

$$\text{LA} = 0.75 \times (\text{s} \times \text{h})$$

where "LA" is leaf area, "s" is maximal width of the leaf, "h" is the maximal length of the leaf.

In knowledge of LA, LAI was calculated using the following formula:

$$\text{LAI}_0 = \frac{\text{LA}_0 \times \text{LN} \times \text{PN}}{\text{T}}$$

where "LAI_0" is leaf area index, "LA_0" is the area of the average-sized leaf of the given species, "LN" is the average number of leaves per plant, "PN" is the number of plants on the experimental area, “T” is the size of the experimental area (RICHTER, 2009).

Leaf relative water content

The effect of organic amendments on plant water status was examined through RWC. Leaf sampling was carried out on 22 August 2023. 5 × 5 cm leaf disc samples were cut from the uppermost, fully developed leaves from 3 plants (BBCH 79) per plot. A total of 9 samples were processed per treatment (3–3 leaves from 3 plants). RWC was determined by the modified method of BARRS & WEATHERELEY (1962). The samples were immediately weighted on analytical scales, then they were soaked in deionized water in petri-plates overnight, to reach their turgid weight. After that, they were put into an oven on 50±5 °C for 48 hours, in order to determine their dry weight.

RWC was estimated using the following formula:

$$\mathrm{RWC}\ (\%) = \left(\frac{\mathrm{FW} - \mathrm{DW}}{\mathrm{TW} - \mathrm{DW}}\right) \times 100$$

where “RWC” is leaf relative water content, “FW” is fresh weight, “DW” is dry weight and “TW” is turgid weight (YAMASAKI and DILLENBURG, 1999).

Statistical analysis

The significant differences between the means of the experimental treatments were tested by two-factor factorial analysis of variance (ANOVA), one factor being the organic amendment application and the other the mineral N level. Significantly different treatments were identified with Tukey’s HSD *post hoc* test. Analysis of regression was also applied.

Results and discussion

Macronutrient content (%) of plant- and grain samples

Both organic amendments treatment ($P = 0.03$) and N fertilizer treatment ($P < 0.05$) had a significant effect on the N-content (*Figure 1*) of maize biomass, but their interaction did not ($P = 0.258$). PHELPS et al. (2013) concluded that increasing N fertilizer rate causes an increased N accumulation in some maize cultivars. The highest values of N% – which were 1.12 times higher than in NPK and 1.06 times higher than in NPK+GM+SR on the average – were measured in NPK+M. Based on the Tukey HSD test with α 0.05 the positive effect of farmyard manure on N% can also be verified. N% in NPK+M was significantly higher than in NPK ($P = 0.023$), but between the other combinations of organic amendments treatments no significant differences ($P = 0.343$; $P = 0.358$) were observed. In their study ZHAI et al. (2024) have also described the positive effect of organic fertilizers on N% of maize biomass. They concluded, that the substitution of 15–30% of chemical fertilizers with cow manure, containing an equivalent quantity of N increases post-silking N uptake, according to improved soil N availability and reduced N losses.

In terms of P% (*Figure 1*), neither the effect of organic amendments treatment (P = 0.269), nor the effect of N doses (P = 0.359) was detectable.

In case of K% (*Figure 1*), the values varied within a very narrow range from 0.58% to 0.73%, but the K% contents of NPK+M were significantly higher than in NPK (P = 0.045) and NPK+GM+SR (P = 0.005).

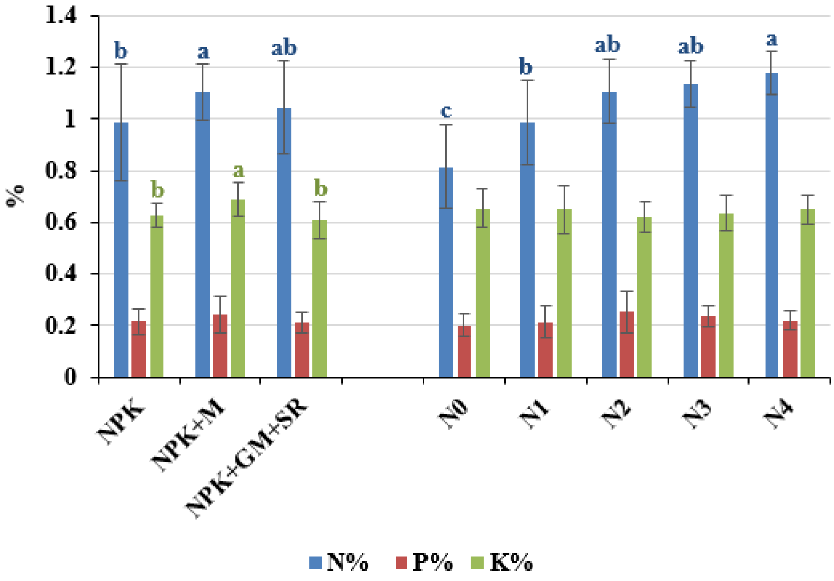

Figure 1

Average N, P and K content (%) of maize aboveground biomass, depending on the variants of organic amendments and nitrogen treatment

Note: NPK = chemical fertilization; M = farmyard manure; GM = green manure; SR = stem residues; N_0–N_4 = 0–70–140–210–280 kg N ha^{-1}. Error bars show standard deviations of means. Different letters upon the bars indicate significant differences among the treatments at P < 0.05 level.

Organic amendments treatment (P = 0.01) and N treatment (P < 0.05) have also influenced N% of maize grain significantly, but there was no statistically verifiable (P = 0.071) interaction between them (*Figure 2*). Based on the Tukey HSD test with α 0.05, N% of NPK+M – which had the highest values among the three treatments – differed significantly both from NPK (P = 0.014) and NPK+GM+SR (P = 0.037). These results are in agreement with the significant effects of organic supplementation on N uptake by plants reported by several researchers (SHAH & ISHAQ, 2006; BASAK et al., 2013). N% of NPK+M could reach higher values mostly at the lower N-doses, thanks to the N-content of easily decomposable organic matter.

In case of P% there were low, but detectable differences. Average grain P% of the treatments were 0.28% by NPK, 0.34% by NPK+M and 0.32% by NPK+GM+SR (*Figure 2*). A significant difference can be observed between NPK and NPK+M

(P = 0.004) and NPK and NPK+GM+SR (P = 0.05). These findings are in consonance with the results of MUNYABARENZI (2014), based on which N and P uptake of maize grain and nutrient use efficiencies were significantly higher in combined treatments, than in treatments treated either with inorganic or organic fertilizers alone.

K% of grains was neither affected by organic amendments treatment (P = 0.531), nor by nitrogen treatment (P = 0.071). Similar results were obtained by BALLA (1960) according to which the potassium content of the grain changes the least as a result of organic amendments.

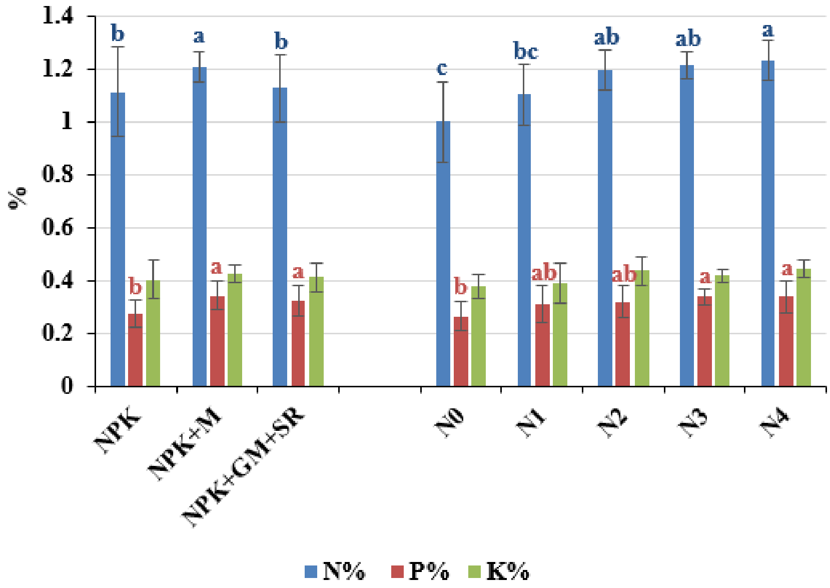

Figure 2
Average N, P and K content (%) of maize grain, depending on the variants of organic amendments and nitrogen treatment. Note: see *Figure 1*

Harvest index and N use indices

On the average, HI [%] of NPK+M and NPK+GM+SR treatments were 1.06 and 1.05 times higher than in NPK (*Table 1*). $HI_{N\%}$ shows that P0023 maize hybrid absorbed 58.63–75.66% of total N in the grain (*Table 1*). In terms of NutE, N doses account for most of the variabilities, i.e., NutE values decreased on the higher N levels (*Table 1*). The smallest deviation between the yields – which was also reflected in the values of AE – was observed by NPK+M. Meanwhile, on the NPK and NPK+GM+SR treatments, AE values decreased on the higher N levels (*Table 1*). In addition to soluble N source, mature farmyard manure contains easily decomposable organic matter, which enhances microbial activity, mineralization and nutrient availability, so manured treatments with a lower dose of chemical N were able to reach higher yields, than NPK or NPK+GM+SR on the same N level. This phenomena was also observed by MAHMOOD et al. (2017). The utilization of 1 kg N fertilizer for the extra yield above the yield of the individual control was 0.37–1.35 kg, decreasing mostly on the higher N levels (AREN) (*Table 1*). According to the results of the database of Hungarian long-term field trials comparing the effect of equivalent nutrients given in the form of farmyard manure or fertilizers, farmyard manure N proved to be 50% as effective in yield increases as fertilizer N was (ÁRENDÁS & CSATHÓ, 1994).

Table 1

Indices characterising N utilization of P0023 maize hybrid when applying supplemental farmyard manure (M), green manure (GM) and stem residues (SR), in addition to inorganic fertilizers (NPK), at equidistantly increasing N doses (N_0–N_4 = 0–70–140–210–280 kg N ha^{-1}). The different letters in the same column indicate distinct difference (P < 0.05).

Treatment	HI	$HI_{N\%}$	NUtE	AE	AREN
N0PK	55.29±6.83	70.97±4.49	78.31±05.84	-	-
N1PK	58.24±3.32	69.29±8.25	70.69±13.40	39.64±36.39	0.87±1.06
N2PK	57.12±0.82	64.98±9.25	53.12±10.01	35.40±08.68	1.14±0.42
N3PK	57.08±6.58	60.90±7.61	49.62±05.90	28.34±13.69	0.92±0.21
N4PK	55.03±7.75	59.86±8.65	49.94±07.01	28.21±02.72	0.83±0.14
N0PK+M	62.82±2.82	75.66±7.78	65.61±09.62	-	-
N1PK+M	59.03±2.26	62.99±4.50	53.17±04.33	09.37±35.64	0.80±0.44
N2PK+M	60.34±4.07	63.92±7.19	53.27±08.03	08.83±11.52	0.51±0.30
N3PK+M	59.79±3.64	66.94±5.70	55.11±07.26	10.38±07.29	0.37±0.25
N4PK+M	58.90±2.06	61.63±4.73	49.03±04.10	13.68±04.54	0.53±0.15
N0PK+GM+SR	56.61±5.04	68.91±8.31	74.67±07.94	-	-
N1PK+GM+SR	61.20±0.31	70.02±5.42	62.05±03.45	58.07±11.37	1.35±0.10
N2PK+GM+SR	62.51±1.91	66.90±6.62	58.23±02.15	45.41±04.08	1.07±0.04
N3PK+GM+SR	59.06±1.99	61.16±7.70	51.18±05.83	29.33±01.65	0.91±0.17
N4PK+GM+SR	58.36±3.07	58.63±1.49	47.45±01.93	18.04±08.40	0.69±0.21
Organic amendments effect					
NPK	56.55^{b}	65.2	60.34	32.90^{a}	0.94^{a}
NPK+M	60.18^{a}	66.23	55.24	10.56^{b}	0.55^{b}
NPK+GM+SR	59.55^{ab}	65.12	58.72	17.14^{a}	1.00^{a}
Nitrogen effect					
N0	58.24	71.84^{a}	72.86^{a}	-	-
N1	59.49	67.43^{ab}	61.97^{b}	35.69	1.01
N2	59.99	65.27^{abc}	54.87^{c}	29.88	0.91
N3	58.64	63^{bc}	51.97^{c}	22.68	0.73
N4	57.43	60.04^{c}	48.8^{c}	19.98	0.68
Pooled SEM	4.08	7.35	11.34	20.52	0.42
P-values					
Organic amendments effect	0.048	0.885	0.152	0.001	0.02
Nitrogen effect	0.701	0.012	<0.001	0.202	0.29
Interaction	0.768	0.718	0.187	0.410	0.72

Abbreviations: HI = harvest index; $HI_{N\%}$ = nitrogen harvest index; NUtE = nitrogen utilization efficiency; AE = agronomic efficiency; AREN = apparent recovery efficiency of nitrogen.

Relationships between vegetative indicators and yield

Only slight, statistically undetectable differences (P = 0.855–0.303) were observed between the dry aboveground biomass weights of organic amendments treatments (*Figure 3*). With an adequate water supply, the effect of organic amendments is enhanced (OGOLA et al., 2002). Since the water supply of the crop year of 2023 was favorable for maize, the plants could probably approach their achievable green biomass at the given nutrient level and the positive effects of organic amendments rather manifested in grain yields. The average grain yield in the NPK+M treatment (225.63±30.9 g/plant) was significantly higher (P = 0.018) than in NPK (198.05±45.16 g/plant), but there was no significant difference between NPK+GM+SR (216.32±37.02 g/plant) and NPK (P = 0.149). N treatment has had a significant effect on both biomass weight ($P < 0.05$) and grain yield ($P < 0.05$). The values of the polynomial and exponential functions – describing dry biomass weight and grain yield increasing with N dose – were appropriate (R^2 = 0.968–0.998) for all three organic amendments treatments. Significant positive relationships can also be observed between dry biomass weight and grain yield of all 3 organic amendments treatments (NPK: r = 0.937, P = 0.019; NPK+M: r = 0.971, P = 0.006; NPK+GM+SR: r = 0.88, P = 0.049). Positive correlation between aboveground dry matter production and grain yield was also reported similarly in other studies (WAJID et al., 2007; ULLAH et al., 2011) (*Figure 3*).

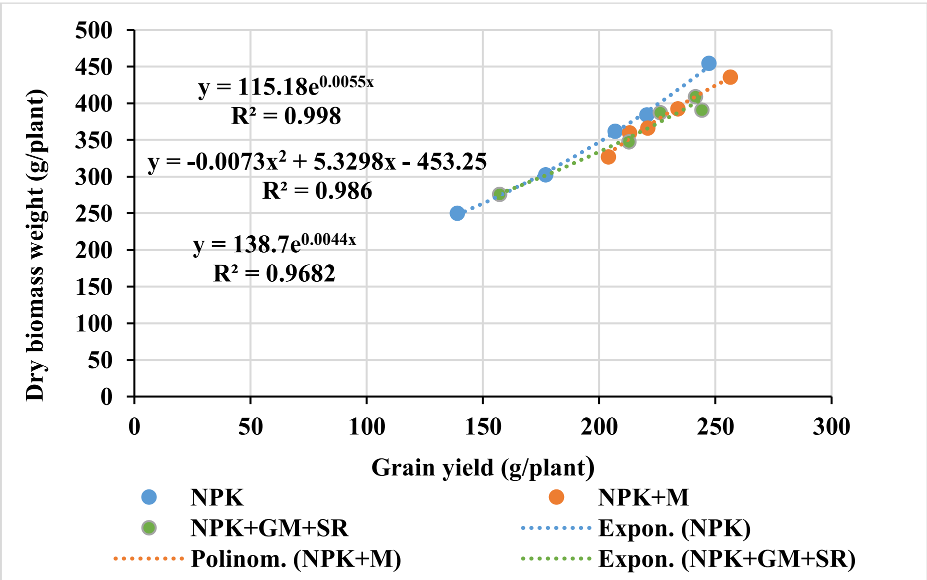

Figure 3

The correlation between dry biomass weight and grain yield of P0023 maize hybrid with the application of chemical fertilizers (NPK) and additional farmyard manure (M), green manure (GM) and stem residues (SR) at equidistantly increasing N doses (N_0–N_4 = 0–70–140–210–280 kg N ha^{-1})

Based on the results of the two-way ANOVA, N treatment had a significant effect ($P = 0.001$) on LAI, but the Tukey HSD test with α 0.05 did not show significant differences ($P = 0.078–0.939$) between control and organic amendments treatments (*Figure 4*). LAI values ranged from 3.67 to 5.12. LYKHOVYD et al. (2019) concluded, that the maximum productivity of maize can be achieved at LAI values ranging from 4 to 5. This statement is in accordance with our results. The fit of the exponential and polynomial curves were appropriate ($R^2 = 0.760–0.968$) in case of all three organic amendments treatments. Significant positive correlations were observed between the LAI and grain yield of all 3 organic amendments treatments (NPK: $r = 0.9$, $P = 0.037$; NPK+M: $r = 0.983$, $P = 0.003$; NPK+GM+SR: $r = 0.784$, $P = 0.117$). BOCZ et al., (1996), also documented the correlation between LAI and grain yield. SZABÓ et al. (2022) also examined the relationship between LAI and grain yield of maize. According to their results, LAI increased grain yield only to a certain extent, after which the increase in LAI did not affect grain yield.

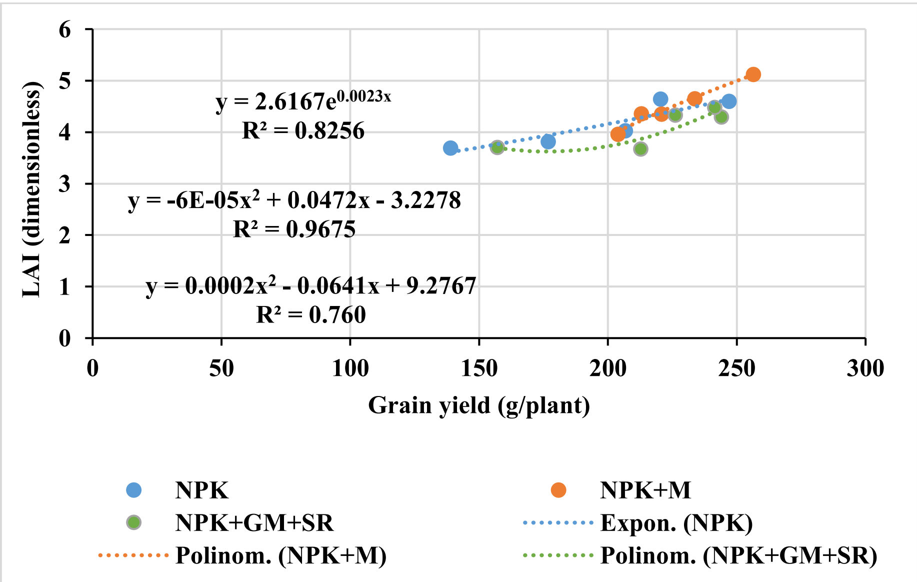

Figure 4
The correlation between the leaf area index (LAI) and grain yield of P0023 maize hybrid with the application of chemical fertilizers (NPK) and additional farmyard manure (M), green manure (GM) and stem residues (SR) at equidistantly increasing N doses ($N_0–N_4$ = 0–70–140–210–280 kg N ha^{-1})

Leaf relative water content (RWC)

Organic amendments treatment had a significant effect ($P < 0.05$) on the RWC of leaves (*Figure 5*), but N treatment did not ($P = 0.737$). Based on the results of the Tukey HSD test with α 0.05, the RWC of NPK+GM+SR differed significantly from NPK ($P < 0.05$) and NPK+M ($P < 0.05$). These results can be explained based on aggregate stability. Formerly DUNAI & TÓTH (2015) carried out researches on aggregate stability in IOSDV. They concluded that NPK+GM+SR treatment had a beneficial effect on the stability of soil macro-aggregates, compared to control and the manured treatment (~9% greater macro-aggregate stability). CHRO-RONG et al. (2023) have published almost similar result. They also found that, the water-stable aggregate ratio (%) in GM treatment is significantly higher, than in NPK. A developed pore network contributes to better water infiltration, water movement and soil water retention (FREDLUND & XING, 1994), which consequently results in advanced water absorption of maize. This is especially important in arid crop years.

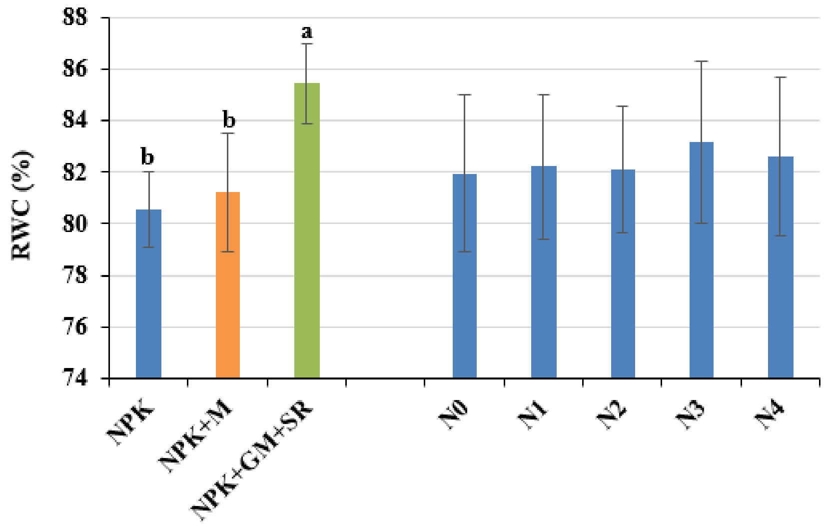

Figure 5

The effects of organic amendments: chemical fertilization (NPK); farmyard manure (M); green manure (GM); stem residues (SR) and N doses (N_0–N_4 = 0–70–140–210–280 kg N ha^{-1}) on the leaf relative water content (RWC) of P0023 maize hybrid. Error bars show standard deviations of means. Different letters upon the bars indicate significant differences among the treatments at $P < 0.05$ level.

Conclusion

The positive effects of organic amendments (especially farmyard manure) were particularly noticeable on smaller doses of N, therefore they should be used to reduce inorganic fertilizer application rate and the resulting environmental risks. Since grain yield ($P = 0.026$), N% content in dry biomass ($P = 0.026$) and N% in grains ($P = 0.014$) were generally higher in case of NPK+M than in NPK control, a wider use of farmyard manure would be advisable in Hungary, in order to improve yields and maize grain quality. Data on RWC indicates that NPK+GM+SR treatment may play a greater role in drier crop years. As soil properties can be influenced by weather conditions, the utilization of fertilizers and the nutrient uptake characteristics of crops can also be modified. Since the present study was carried out among favorable conditions, it would be worthwhile to conduct the same experiment in an arid crop year, to compare the results and to model the vintage effects. The results of our IOSDV field trial confirm the correctness of the principle of cost-saving and environmentally friendly fertilizer recommendation systems, i.e., that organic amendment application diminishes the amount of mineral N(PK) recommended.

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