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Organic and mineral nitrogen fertilizers in sweet maize (*Zea mays* L. *saccharata* Sturt.) production under temperate climate

Franc BAVEC, Martina BAVEC, Milojka FEKONJA

University of Maribor, Faculty of Agriculture and Life Sciences
Pivola 10, 2311 Hoče, Slovenia
E-mail: franci.bavec@uni-mb.si

Abstract

The introduction of sweet maize (*Zea mays* L. *sacharata* Sturt.) into temperate climates requires additional information concerning fertilization, especially for developing organic production system. Field experiments were carried out in the Slovenian region Styria suitable for growing only early-maturity maize hybrids (FAO 100–400) with the aim of determining the effects of nitrogen applied to different nitrogen target values (70, 120, 170 and 220 kg ha^{-1} N) on growth, yield, photosynthetic activity and soil mineral nitrogen (N_{min} – NO_3-N and NH_4-N) dynamics, as compared to the control. Nitrogen was applied as organic by-products (pumpkin cake and pig manure digestate) and mineral fertilizers (CAN 27 and ENTEC®26). The major points were as follows: 1) pumpkin cake had a similar effect to that of mineral fertilizers, and gave significantly higher total and marketable yields (14.476 and 11.619 t ha^{-1}, respectively), higher values of cob characteristics and plant mass than for pig manure digestate; 2) there were no significant differences in total and marketable yields among the target values of 120, 170 and 220 kg ha^{-1} N, but calculated nitrogen target value expressed as the peak of a regression curve for yield was 170 kg ha^{-1} N. However, the data showed that high yields of organic sweet maize can be obtained using pumpkin cake as nitrogen fertilizer based on target value 120 kg ha^{-1} N (rate of kg ha^{-1} N = 120 kg ha^{-1} N – soil N_{min} till 0.9 m depth) at the time of sowing.

Key words: nitrogen, organic farming, photosynthesis, yield, *Zea mays*.

Introduction

Sweet maize (*Zea mays* L. *saccharata* Sturt.) is a new potential crop for temperate climates but requires additional agronomic improvements (Fekonja et al., 2011) and development due to climatic changes (Genc et al., 2013). The total area of sweet maize in the European warmer climates is 73600 ha (Westen van der, 2008). Hungary and France represent the largest European producers with 31000 and 25600 ha, respectively. Of the total 350 000 ha production area of sweet corn worldwide, only 20% is in the EU (Anonymous, 2009), produced mainly in non organic cultivation system.

As well known, nitrogen (N) is one of the most limiting factors for organic plant production, and there is a lack of information concerning N supply in relation to growth, yield and mineral N (N_{min}) residues under temperate climate, although there are the examples of some other vegetables (Feller, Fink, 2002). Excessive use is a concern, since large amounts of N can remain in the soil after harvesting the crop (Neeteson et al., 1999) – this N includes residual soil N_{min} and N in crop residues. The recommended rates of N may also leave large amounts of residual N_{min} in the case of other field vegetables, especially if they are harvested before maturity. To avoid large amounts of N residues in soil after harvest, organic manures and wastes (Burgos et al., 2006) with higher N content (>1.5%) and C:N ratios under 20 can be used. In this way N mineralization in the soil parallels the requirements of the crops for uptake of N (Amlinger et al., 2003; Bavec et al., 2006).

New N fertilizers derived from plant processing (e.g., by-products) are becoming also important (Holm-Nielsen et al., 2009), especially in sustainable farming production (Adelekan et al., 2010), as organic farming where artificial mineral N fertilizers are not allowed (EC 834/2007, EC 889/2008). Olaniyan et al. (2004) investigated the effects of N fertilizer sources (organo-mineral, poultry manure and NPK) and N rates (0, 40, 80 and 120 kg ha^{-1} N) on the growth and yield of sweet maize in warmer Turkish climate than in Slovenia. Their results suggest that organo-mineral fertilizers may be useful to reduce nitrate leaching losses and to improve soil structure – the highest yield and total dry matter were achieved at 120 kg ha^{-1} N. Raja (2001) and George and Eghbal (2003) showed similar results. Photosynthesis in plants exploits the Sun's radiation energy for the oxidation of water and the reduction of carbon dioxide into organic compounds (Taiz, Zeiger, 2002). Xu et al. (2004) noted that an increase in photosynthetic activity of sweet maize and the quantity of dry matter might be associated with stomatal opening and biochemical activities, and Efthimiadou et al. (2009) concluded that photosynthetic rates significantly differed among fertilizers, zero treatments and rates of fertilizing.

Because sweet maize is not commercially produced plant under temperate climate (non-typical growing conditions), and even organic principles of its production are rather unknown, the aim of this research was i) to compare suitability of organic N fertilizers with commonly used mineral N fertilizers, ii) to define target value for soil N_{min}, iii) to evaluate the amount of mineral N in the soil at harvest and iv) to analyse their effects on growth and yield parameters, including photosynthetic activity.

Materials and methods

A three-year (2007–2009) experiment was conducted with the aim of investigating the effects of different organic by-products (pumpkin cake from oil processing (9.6% N) and pig manure digestate from biogas production (1.6, 3.7 and 4.8 % N years, respectively) and mineral fertilizers (CAN 27 and ENTEC®26 – long term N release fertilizer, containing 3.4 dimethylpyrazol phospahate, 7.5% NO_3-N and 18.5% NH_4-N) applied at N target values of 70, 120, 170 and 220 kg ha^{-1} N (N_{70}, N_{120}, N_{170} and N_{220}, respectively), compared with control plots (CON) – considering N_{min} values in the soil (NO_3-N and NH_4-N) before sowing – on yield, growth and N dynamics in the soil. The experiment was designed as a randomized block with four replications, and was located in north-eastern Slovenia, at the University Research Centre Maribor (46°39′ N, 15°41′ E and 282 m a.s.l.). The climate characteristics of experimental location (Table 1) are appropriate only for growing early maturity maize hybrids (FAO 100–400).

Table 1. Average temperature and the sum of rainfall at the Weather Station in Maribor during the seasons 2007, 2008, and 2009 in comparison to the 20-year average (+ or −)

	Month					Average Sum
	May	June	July	August	September	
2007 growing season						
Temperature °C	17.2 (+1.8)	21.2 (+2.8)	22.4 (+1.9)	20.2 (+1.1)	13.9 (+1.9)	19.0
Rainfall mm	134 (+34)	60 (−66)	112 (+3)	129 (+9)	173 (+69)	608
2008 growing season						
Temperature °C	15.9 (+0.5)	20.2 (+1.8)	21.3 (+0.8)	20.7 (+0.6)	14.9 (−0.9)	18.6
Rainfall mm	35 (−65)	96 (−30)	110 (+1)	134 (+14)	61 (−43)	436
2009 growing season						
Temperature °C	17.1 (+1.7)	18.5 (+0.1)	21.5 (+1)	21.2 (+1.1)	17.1 (+1.3)	19.1
Rainfall mm	130 (+30)	165 (+39)	127 (+18)	284 (+164)	103 (−1)	809
20-year (1981–2000) period						
Temperature °C	15.4	18.4	20.5	20.1	15.8	18.0
Rainfall mm	100	126	109	120	104	559

Each plot area was 17.5 m^2, with the preceding crop being clover. Zadoks et al. (1974), i.e. BBCH scale was used to score plant growth and development. Plant density (hybrid cv. 'Gold Cup F1') was eight plants m^{-2}, the distance between rows was 0.70 m, and the final distance between plants within the row was 0.15 m (stands were thinned at BBCH 12 stage). The soil was sandy-loam, with fertilization done on the basis of A-L method (12.3 g kg^{-1} P_2O_5, 16.2 g kg^{-1} K_2O) of the soil, and was fertilized with (KCl containing 60% K_2O) and raw phosphate (containing 33% P_2O_5). Before sowing, N_{min} within the 0–0.90 m soil depth (Scharf, Wehrmann, 1975) was analyzed. Samples were taken three times during the season: at growth stage BBCH 15–17 (5–7 developed leaves), at BBCH 65–67 (brooming), and at BBCH 75–79 (milk) stage.

Total yield (i.e. cobs with husks) and marketable yield (i.e. cobs without husks) were harvested at growth stage BBCH 75–79 from an area of 10 m^2, which represented the middle three rows in each plot. At BBCH 75–79, the cob and plant characteristics of sweet maize were analyzed on 10 plants per plot (randomly selected). The measured parameters were: fresh cob mass with husks, cob mass without husks, plant mass with cobs, plant mass without cobs – green mass, cob length, cob diameter and the number of rows per cob. During the growing season, photosynthetic rate (A) and photosynthetic epidermal (stomatal) conductance (g_s) were measured simultaneously in the field. Measurements were performed at three growth stages of sweet maize (i.e. BBCH 15–17, 65–69 and 75–79 stages) by gas-exchange equipment LCpro+ (ACD BioScientific Ltd., UK). Measurements were repeated five times at 1-min intervals on two plants per plot, and their mean used as the measured value.

An analysis of variance (*ANOVA*; $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$) was performed using the statistical package *Statgraphic®Centurion* (2005). Significant differences among treatments were determined by Duncan's multiple range test at $P < 0.05$. Pearson's correlation coefficients between total and marketable yields, and cob and plant characteristics were calculated by *SPSS 15.0* for *Windows* (2005) statistical package. A quadratic regression curve was calculated and the N_{min} target value determined according to the parabola's apex.

Results and discussion

Mineral nitrogen (N_{min}) in the soil. Before sowing N_{min} was 17.3–19.2 kg ha^{-1} N_{min} in the soil and increased to 63 kg ha^{-1} N_{min} for the control treatment at

BBCH 15–17 stage (Table 1). At this growth stage N_{min} varied significantly with different fertilizers, nitrogen target values, years (except in the 0–0.30 cm soil layer) and their interactions. The N_{min} (0–0.90 m layer) significantly increased from pig manure digestate, CAN 27, and pumpkin cake to ENTEC®26 (76, 96, 107 and 131 kg ha^{-1} N, respectively); however, there was no significant difference between pumpkin cake and CAN 27. When the soil was separated into layers, similar results of N_{min} were achieved in the 0–0.30 m soil layers. In the 0.30–0.60 m layer, N_{min} for the ENTEC®26 treatment was significantly higher than for CAN 27 and digestate treatments. It can be explained by differences in N leaching and mineralisation. In the 60–90 cm layer, N_{min} for ENTEC®26 was significantly higher than for the other treatments. The use of ENTEC®26 showed an effect by the first measured growth stage, indicating a long fertilizing effect in comparison to the other fertilizers; however, this changed in the next two measured growth stages. With increased nitrogen target values (comparing the control plot to 220 kg ha^{-1} N), at BBCH 15–17 stage (0–0.90 m layer) N_{min} significantly increased from 63 to 134 kg ha^{-1} N. There was the same trend in the 0.30–0.60 m layer, where N_{220} significantly differed from N_{170}, N_{70} and control treatments. In the 0.60–0.90 m layer, all treatments where nitrogen was added had significantly higher N_{min} values compared to the controls; and of these only N_{170} and N_{120} were significantly different from each other.

There were significantly lower N_{min} in comparison to other fertilizers for pig manure digestate, at BBCH 65–67 (0–90 and 0–30 cm layers) and at BBCH 75–79 (0–0.90 and 0.30–0.60 m layers) stages. N_{min} (0–0.90 cm layer) fell rapidly for all used fertilizers at the BBCH 65–67 stage (Table 2), as growth and use of nitrogen was very intense. At harvest (BBCH 75–79), N_{min} values remained constant or similar to at BBCH 65–67 stage. This is consistent with the report of Beckingham (2007) that sweet maize consumes 60% of the N required for growth, 14 d before and 14 d after brooming. There were no significant differences between low N_{min} values at BBCH 65–76 and 75–79 stages for all used fertilizers in the 0.60–0.90 m layer. However (in the case of used fertilizers), the values did not exceed the residual N_{min} value of 80 kg ha^{-1} N (up to 0.90 m in depth) allowed after harvest (in accordance with the guidelines for integrated vegetable production) (IPZ-TN, 2013) and acceptable for organic farming due to nitrate directive. Furthermore, N_{min} values tended to increase with the increased nitrogen target values (at all growth stages and in all soil layers that were analyzed). The highest nitrogen target value (N_{220}) resulted in the highest N_{min} values in the upper two soil layers (i.e. 0–0.30 and 0.30–0.60 m layers) for all measured growth stages.

Table 2. Mineral nitrogen (N_{min}) (NO_3-N + NH_4-N) dynamics at three sweet maize growth stages (BBCH 15–17, 65–69 and 75–79) and at different soil layers (averaged across the three years)

Growth stage	BBCH 15–17				BBCH 65–67				BBCH 75–79			
Depth (cm)	0–30	30–60	60–90	0–90	0–30	30–60	60–90	0–90	0–30	30–60	60–90	0–90
Treatment	kg ha^{-1} N_{min}											
Fertilizer (F)	***	**	***	***	**	***	ns	***	***	**	ns	***
Nitrogen target value (N)	***	***	***	***	***	***	***	***	***	***	***	***
Year (Y)	ns	*	***	***	***	***	***	*	***	**	***	***
Interactions												
F × N	***	***	***	***	***	***	***	***	***	***	***	***
N × Y	***	***	***	**	***	***	***	**	***	***	***	**
F × Y	***	***	***	***	***	***	***	**	***	***	***	***
Fertilizer												
Pumpkin oil cake	56 b	31 ab	20 b	107 b	39 a	13 bc	9	61ab	31 b	18 a	9	58 ab
Digestate	32 c	26 c	18 bc	76 c	19 b	11 c	10	40 c	23 c	10 b	8	41 c
CAN 27	54 b	27 bc	15 c	96 b	34 a	16 ab	9	59 b	29 bc	16 a	9	54 b
ENTEC®26	75 a	32 a	24 a	131 a	35 a	21 a	10	66 a	43 a	16 a	9	68 a
Nitrogen target value kg ha^{-1} N												
CON	29 d	20 c	14 c	63 e	18c	11 c	7 b	36 c	21 c	6 d	6 c	33 d
N_{70}	38 c	27 b	20 ab	85 d	23ab	13 bc	8 b	44 c	27 bc	11 c	8 b	46 c
N_{120}	62 b	31 ab	18 b	111 c	33b	14 bc	8 b	55 b	28 bc	17 b	8 b	53 bc
N_{170}	65 b	30 b	24 a	119 b	32b	16 b	12 a	60 b	33 b	18 b	9 b	60 b
N_{220}	78 a	36 a	20 ab	134 a	52a	22 a	12 a	86 a	48 a	22 a	13 a	83 a
Year												
2007	55	30 b	19 b	104 b	38 a	10 b	6 c	54 b	37 a	17 a	7 b	61 a
2008	54	17 c	13 c	84 c	31 ab	13 b	10 b	54 b	39 a	15 a	8 b	62 a
2009	54	41 a	25 a	120 a	26 b	23 a	12 a	61 a	18 b	12 b	11 a	41 b

CON – control treatment without added N fertilizers; *, **, *** – significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively; ns – not significant; a, b, c indicates significant differences within the column, according to Duncan's multiple range test at $P < 0.05$

There were significant differences between experimental years (Table 2). The main effect on N mineralization in the soil is suitable soil humidity (Sierra, 1996). In our case, there were considerable differences in rainfall amount between experimental years. Compared to 2009, at BBCH 15–17 stage in 2007 and 2008 the soil N_{min} (0–0.90 m layer) was significantly lower with the lack of rainfall in June 2007 and May–June 2008, and N_{min} was lower in the deeper soil layers (30–60 and 60–90 cm layers). There were significant variations in N_{min} for the 0–90 cm layer in 2009: in the middle of the 2009 season (BBCH 65–67), higher soil humidity resulted in accelerated nitrogen mineralization; and at the end of the season (BBCH 75–79), significantly lower N_{min} can be ascribed to August's 45% increase in rainfall (compared to the long-term average) and resultant N leaching (Neeteson et al., 1999). N_{min} residues at BBCH 75–79 in the 0.60–0.90 m layer during 2009 resulted in significantly higher N_{min} compared to the two upper layers of soil and to the years 2007 and 2008, and was associated with higher rainfall in August 2009.

Plant mass and yield. The cob mass without husks significantly differed between nitrogen target values and between years (Table 3). Cob mass with husks and number of grain rows also differed due to the use of different nitrogen fertilizers. There was no significant effect of N fertilizers and nitrogen target values on cob diameter and green mass. There were significant differences between organic nitrogen fertilizers: fertilizing with pumpkin cake gave a significantly higher cob mass with husks, cob length, the number of grain rows, and plant mass than fertilizing with pig manure digestate. There were no significant differences among pumpkin cake, CAN 27 and ENTEC®26.

The increased nitrogen target value did not increase cob mass with and without husks, and there was a significant difference only between the control plot and treatments where nitrogen was added. Bavec (1992) found out that higher N rates than 150 kg ha^{-1} because of existing soil N_{min} to the target values 225 no 325 kg ha^{-1} N did not increase grain yields for common maize. However, Maga et al. (2006) and Efthimiadou et al. (2009) reported that increasing nitrogen rates lead to increased cob mass of sweet maize. The differences between results may be a consequence of the fertilizers used, plant densities, and soil and climatic conditions. Furthermore, in the case of nitrogen target values, significant differences were more expressed in cob length: fertilizing with N_{170} and N_{220} resulted in significantly greater cob length compared with N_{70} or control. The higher nitrogen target value of N_{220} differed significantly from N_{70} and control plots in the number of grain rows; the use of pig manure digestate resulted in significantly lower cob and plant parameters in comparison to all other fertilizers. Plant mass was also significantly affected by fertilizer, nitrogen target value and year. Plant mass at nitrogen target values N_{220} and N_{170} was significantly higher than for N_{70} and control treatments. It is possible that hailstorms in 2008 reduced plant mass in comparison to 2007 and 2009. There were significant differences in green mass between years due to 45% more rainfall in 2009 (significantly higher values) in comparison to the 20-year average.

Table 3. Effect of nitrogen fertilizers, nitrogen target values and experimental years on cob and plant characteristics of sweet maize

Treatment	CMh	CM	CL	CD	NGR	PM	GM
	g cob^{-1}	g cob^{-1}	cm	cm		g $plant^{-1}$	g $plant^{-1}$
Fertilizer (F)	*	ns	*	ns	**	*	ns
Nitrogen target value (N)	***	***	***	ns	***	***	ns
Year (Y)	***	***	***	*	***	***	***
Interactions							
F × N	ns	ns	ns	ns	Ns	ns	ns
N × Y	*	*	***	ns	Ns	ns	ns
F × Y	ns	ns	ns	ns	*	ns	ns
Fertilizer							
Pumpkin oil cake	302.6 a	247.9	17.6 a	5.0	16.6 a	689.2 a	386.7
Digestate	279.5 b	229.9	16.8 b	4.8	15.4 b	638.4 b	360.4
CAN 27	294.8 ab	234.6	17.6 a	5.2	16.5 a	663.0 ab	376.4
ENTEC®26	295.5 ab	235.4	17.6 a	5.4	16.4 a	665.1 ab	370.5
Nitrogen target value kg ha^{-1} N							
CON	256.6 b	205.3 b	16.2 c	5.1	15.2 c	611.7 c	355.1
N_{70}	290.7 a	235.3 a	17.1 b	5.4	16.0 b	649.4 bc	370.2
N_{120}	301.1 a	242.7 a	17.7 ab	4.8	16.3 ab	672.8 ab	372.3
N_{170}	308.0 a	250.1 a	17.9 a	4.9	16.7 ab	696.0 a	388.2
N_{220}	309.0 a	251.5 a	18.1 a	5.3	17 a	689.7 a	381.7
Year							
2007	239.1 c	199.8 b	16.3 b	4.8 b	15.7 b	486.0 a	247.2 c
2008	262.2 b	214.3 b	16.4 b	4.8 b	15.5 b	640.0 b	378.6 b
2009	378.0 a	296.7 a	19.5 a	5.6 a	17.5 a	865.9 a	494.7 a

CON – control treatment without added N fertilizers, CMh – fresh cob mass with husks, CM – fresh cob mass without husks, CL – cob length, CD – cob diameter, NGR – number of grain rows, PM – fresh plant mass, GM – fresh plant green mass; *, **, *** – significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively; ns – not significant; a, b, c indicates significant differences according to Duncan's multiple range test at $P < 0.05$

The year, fertilizer and nitrogen target value had significant effects on total and marketable yield (Table 4). Pig manure digestate produced lower total yield in comparison to pumpkin cake, CAN 27 or ENTEC®26, which were all classified into the same statistical group. Fertilizing with pig manure digestate produced significantly lower marketable yield than the use of CAN 27 and ENTEC®26, but pumpkin cake resulted in significantly higher marketable yield than all other fertilizers (marketable yield of 10.0, 11.1, 11.1 and 12.2 kg 10 m^{-2}, respectively). These values imply that pumpkin cake organic fertilizer was equivalent to mineral fertilizers and could replace them in sweet maize production in temperate climates. In terms of N target values, there were similar significant differences for total and marketable yield, with N_{220} significantly different from N_{70} and control treatments.

Table 4. Effect of nitrogen fertilizers, nitrogen target values and experimental years on total and marketable yield of sweet maize

Treatment	Total yield	Marketable yield
	t ha^{-1}	
Fertilizer (F)	***	***
Nitrogen target value (N)	***	***
Year (Y)	***	***
Interactions		
F × N	ns	ns
N × Y	*	*
F × Y	ns	ns
Fertilizer		
Pumpkin oil cake	15.2 a	12.2 a
Digestate	12.6 b	10.0 c
CAN 27	14.2 a	11.1 b
ENTEC®26	14.1 a	11.1 b
Nitrogen target value kg ha^{-1} N		
CON	12.0 c	9.3 c
N_{70}	13.8 b	10.9 b
N_{120}	14.0 ab	11.3 ab
N_{170}	15.0 ab	11.8 ab
N_{220}	15.3 a	12.2 a
Year		
2007	8.5 c	7.0 c
2008	12.8 b	10.6 b
2009	20.7 a	15.6 a

Total yield – cobs with husks, marketable yield – cobs without husks; *, *** – significant at $P \le 0.05$, $P \le 0.001$, respectively; ns – not significant; a, b, c indicates significant differences within the column, according to Duncan's multiple range test at $P < 0.05$

Prediction of nitogen (N) supply. A regression between yield (y) and available nitrogen (target values) (x) was calculated both as an average of all three years and separately. As an average of all three years the regression was significant ($y = -0.1933x^2 + 66.1852x + 7082.51$) with determination coefficient $R^2 = 0.14$, $P < 0.001$. The nitrogen target value for a yield of 170 kg ha^{-1} N was calculated, based on a quadratic regression curve, and was 30 kg ha^{-1} N lower compared to the recommended value for integrated vegetable production (IPZ-TN, 2013). However, R^2 for the nitrogen target value of sweet maize yield varied depending on the experimental years ($R^2 = 0.10^{ns}$, $R^2 = 0.49$ and $R^2 = 0.39$; $P < 0.001$ for 2007, 2008 and 2009, respectively). These differences may be a result of weather conditions, largely the hailstorms of 2007 and 2008, but regardless of this is an important first basic scientific result under European temperate climate conditions. Similar calculations for this particular climate were done for common maize (Bavec, 1992), which resulted in higher nitrogen target values of up to 330 kg ha^{-1} N. In the present case, the lower N_{min} target values for sweet maize yield, in comparison to common maize, is a result of shorter sweet maize vegetative period, with harvest in the milk growth stage. Our results are similar to the N_{min} target value of 163 kg ha^{-1} N reported in Germany (Feller, Fink, 2002), calculated as an algorithm and data set from the expected N uptake by the crop, the N_{min} residue in the soil at harvest and the apparent net nitrogen mineralization. In other parts of the world, Olaniyan et al. (2004) in a semi-arid region and Raja (2001) in India found out that the highest nitrogen rate used in their experiments (120 kg ha^{-1} N) resulted in the highest cob yields. Furthermore, for sweet maize production Davis (2005) recommended N rates of 170 kg ha^{-1} N in the USA, George and Eghbal (2003) 160 kg ha^{-1} N in Germany, and Beckingham (2005) recommended far more in Australia at 310 kg ha^{-1} N.

Photosynthetic parameters. Photosynthetic rate and stomatal conductance of sweet maize measured at different growth stages (BBCH 15–17, 65–67 and 75–79) were more dependent on climatic conditions of years than on applied N (Table 5). The only exception was the BBCH 15–17 stage, where photosynthetic rate (A1) significantly differed with nitrogen target values. Where no fertilizers were added, photosynthetic rate was significantly lower than in treatments that were fertilized. In a semi-arid region in Greece, Efthimiadou et al. (2009) found that photosynthetic rate of sweet maize significantly differed among organic fertilizers and unfertilized treatment.

We found no significant differences in photosynthetic rate and stomatal conductance between fertilized treatments. The reason for the non-significant effect of different nitrogen target values at the BBCH 65–67 (A2) and BBCH 75–79 (A3) stages can be ascribed to climatic (hailstorms and drought) conditions and N mineralization during the season (2007 and 2008). In 2009, 45% more rainfall than the 20-year average, may have accelerated mineralization (Silgram, Shepherd, 1999), and growth was probably affected by equalized growth conditions in all treatments, because the soil contained a good proportion of organic matter (2.9–3.0%). Furthermore, there was a comparable situation for measured stomatal conductance, with no significant differences between treatments. Stomatal conductance was significantly different only between years. In a Greek semi-arid environment, Efthimiadou et al. (2009) found that only controls significantly differed in stomatal conductance from other investigated fertilized treatments.

Table 5. Effects of examined parameters on photosynthetic rate (A1–A3) and stomatal conductance (g_s1–g_s3) of sweet maize, mean values per plant from the three-year average

Treatment	A1	A2	A3	g_s1	g_s2	g_s3
	μmol m^{-2} s			mol m^{-2} s		
Fertilizer (F)	ns	ns	ns	ns	ns	ns
Nitrogen target value (N)	*	ns	ns	ns	ns	ns
Year (Y)	***	***	***	***	***	***
Interactions						
F × N	ns	ns	ns	ns	ns	ns
N × Y	*	*	*	ns	ns	ns
F × Y	ns	ns	ns	ns	ns	ns
Fertilizer						
Pumpkin oil cake	19.46	18.04	16.17	0.217	0.130	0.143
Digestate	21.53	18.93	16.92	0.212	0.138	0.143
CAN 27	19.44	18.20	17.79	0.212	0.126	0.147
ENTEC®26	20.17	17.60	18.42	0.223	0.134	0.158
Nitrogen target value kg ha^{-1} N						
CON	17.74 b	17.07	16.10	0.207	0.125	0.139
N_{70}	21.18 a	17.19	17.12	0.232	0.131	0.154
N_{120}	20.24 a	17.99	17.85	0.207	0.136	0.158
N_{170}	21.53 a	18.44	17.92	0.223	0.129	0.147
N_{220}	20.04 ab	20.29	17.62	0.210	0.138	0.140
Year						
2007	17.24 b	18.19 b	12.84 c	0.153 c	0.114 b	0.077 b
2008	17.96 b	16.07 c	17.02 b	0.227 b	0.139 a	0.183 a
2009	25.24 a	20.32 a	22.11 a	0.268 a	0.143 a	0.183 a

CON – control treatment without added N fertilizers, a, b, c indicates significant differences within the column, according to Duncan's multiple range test at $P < 0.05$; A1, A2 and A3 – photosynthetic rate at BBCH 15–17, 65–67 and 75–79, respectively; g_s1, g_s2 and g_s3 – stomatal conductance at BBCH 15–17, 65–67 and 75–79, respectively; *, **, *** – significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively; ns – not significant

Conclusions

1. The organic fertilizer pumpkin cake gave significantly higher marketable yield than mineral fertilizers and digestate. Thus, organic nitrogen fertilizer (by-product of oil pumpkin processing) is a suitable plant-derived nitrogen fertilizer for sustainable farming system, especially organic farming. Furthermore, ENTEC®26 known as slow-release nitrogen fertilizer, resulted in the same total yield, morphological parameters in comparison to CAN 27 and pumpkin cake, but residual N_{min} was higher than when using CAN 27 and digestate fertilizers.

2. By increasing N target values (70, 120, 170 and 220 kg ha^{-1} N) at all measured growth stages, N_{min} values (0–0.90 m soil layer) significantly increased, and similar significant effects were also observed for yield and some cob and plant parameters (e.g., cob length, number of grain rows and plant mass). Based on the results of the soil N_{min} and added N, the optimal target value was calculated as 170 kg ha^{-1} N. In the case of using pumpkin cake, the suggested target value is 120 kg ha^{-1} N (rate of kg ha^{-1} N = 120 kg ha^{-1} N – soil N_{min} till 0.9 m depth) at the time of sowing. At this target value, analysed residual N_{min} at harvest is not risky for environmental pollution.

3. The photosynthetic rate significantly differed between nitrogen target values and control treatment without added N only at the growth stage BBCH 15–17, but there were no significant differences in stomatal conductance among fertilization treatments at all growth stages.

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Cukrinio kukurūzo (*Zea mays* L. *saccharata* Sturt.) tręšimas organinėmis ir mineralinėmis azoto trąšomis vidutinio klimato sąlygomis

F. Bavec, M. Bavec, M. Fekonja

Maribor universitetas, Slovėnija

Santrauka

Norint cukrinius kukurūzus pradėti auginti vidutinio klimato sąlygomis, reikia sukaupti papildomos informacijos apie jų tręšimą, ypač juos auginant ekologiškai. Lauko eksperimentai buvo vykdyti Slovėnijos Štirijos regione, kuriame yra tinkamos sąlygos auginti kukurūzų ankstyvuosius hibridus (FAO 100–400). Tyrimų tikslas – nustatyti 70, 120, 170 bei 220 kg ha^{-1} azoto (N) įtaką kukurūzų augimui, derliui, fotosintezės veiklai ir dirvožemio mineralinio azoto (N_{min} – NO_3-N bei NH_4-N) dinamikai ir palyginti su kontroliniu variantu. Azotas buvo įterptas kaip organinis šalutinis produktas (moliūgų išspaudos bei kiaulių mėšlo digestatas) ir mineralinės trąšos (CAN 27 bei ENTEC®26). Tyrimų rezultatai: 1) moliūgų išspaudos turėjo panašią įtaką kaip ir mineralinės trąšos, o jomis patręšus buvo gautas esmingai didesnis bendras prekinis derlius (atitinkamai 14,476 ir 11,619 t ha^{-1}), didesnės burbuolių savybių vertės ir augalų masė, palyginus su tręšimu kiaulių mėšlo digestatu; 2) nebuvo gauta esminių prekinio derliaus skirtumų tarp tręšimo 120, 170 ir 220 kg ha^{-1} N, o apskaičiuota azoto norma, išreikšta kaip regresijos kreivės pikas, derliui buvo 170 kg ha^{-1} N.

Tyrimų duomenys parodė, kad galima gauti didelį ekologiškai auginamų cukrinių kukurūzų derlių, sėjos metu juos tręšiant moliūgų išspaudų kiekiu, atitinkančiu 120 kg ha^{-1} N (norma kg ha^{-1} N = 120 kg ha^{-1} N – dirvožemio N_{min} iki 0,9 m gylio).

Reikšminiai žodžiai: azotas, derlius, ekologinis ūkininkavimas, fotosintezė, *Zea mays*.