Agricultura 12: No 1-2: 31-38 (2015)

DE GRUYTER OPEN

Sweet maize growth and yield response to organic and mineral fertilizers, N rates and soil water regimes

Franc BAVEC[1]*, Martina BAVEC[1], Silva GROBELNIK MLAKAR[1], Milojka FEKONJA[2]
[1]University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10, 2311 Hoče, Slovenia
[2]Development Agency Slovenske gorice, Trg osvoboditve 9, 2230 Lenart

ABSTRACT

Sweet maize is an underutilized vegetable in European temperate areas, and its consumption is increasing. For better understanding of cultivation practices, this pot experiment aimed to determine the effects of different water regimes and nitrogen (N) rates calculated from N target values. N rates of 0 (control), 0.6 and 2 g N pot^{-1} were applied as organic by-products pumpkin cake and pig manure digestate, and mineral fertilizers CAN 27 and ENTEC®26. Treatments of water supply were based on measured soil matric potentials of 2.8 pF (drought stress), 2.6 pF (optimal water) and 2.4 pF (overwatered). In comparison to mineral fertilizers, pumpkin cake proved to be equal in effectiveness in plant height (155.8 cm), cob (85.8 g), green (124.9 g) and leaf mass per plant (44.2 g), or even better in root (72.3 g) and broom mass per plant (3.0 g). Yield parameters, cob mass (70.1 g), its length (6.3 cm) and diameter (2.0 cm), as well as the residual mineral N (59 mg N kg^{-1}) significantly increased at the highest N rate. Significantly lower values of the evaluated morphological parameters and photosynthetic rates (at brooming and harvesting) were associated with drought stress. The matric tension of 2.6 pF was established as an appropriate water regime for sweet maize growth.

Key words: *Zea mays* L. *saccharata* Sturt., nitrogen, fertilizers, soil water potential, growth conditions

INTRODUCTION

In the tropics, from where sweet maize (*Zea mays* L. *saccharata* Sturt.) originates, the most important limiting factors for its growth are water and nitrogen (N) supply (Moser et al. 2006). The crop is grown at latitudes between 50°N and 40°S, and at altitudes 0–3,000 m above sea level (Ghorpade et al. 1998), and to establish sweet maize production in a temperate climate requires research into cultivation practices. Moreover, climate change (i.e. increased temperatures) suggests the possibility of its wider production, which will require further research in areas currently considered atypical for maize (Bavec and Bavec 2002).

Limiting factors for sweet maize production are high temperatures and water stress. High air temperatures (> 38°C) and concurrent water stress decrease yields (Ramadoss et al. 2004). In semi-arid regions, where temperatures are high and problems with water and irrigation are common, Sari et al. (2000) reported that April is the preferred sowing time for cob and yield quality, and that later sowing in May reduces yield. Öktem et al. (2003) recommended a drip irrigation system with two-day irrigation frequency (100 % of evapotranspiration) to achieve optimum growth of sweet maize in semi-arid regions. Stone et al. (2001) analyzed the drought responses of sweet maize water use, biomass, yield, and yield components and found that yield was strongly related to biomass accumulation (especially to biomass accumulated after brooming). Biomass reduction occurred mainly due to the effects of drought stress on radiation use efficiency, particularly at early growth stages.

When considering the growth of sweet maize, special attention needs to be devoted to N nutrition and possible environmental pollution by N residues after harvesting the crop (Silgram and Shepherd 1999). N residues include the residual soil mineral N (Nmin) and N in crop residues. Using

*Correspondence to:
E-mail: franci.bavec@um.si

the recommended N rates for vegetables, however, may leave large amounts of residual soil Nmin, especially if crops such as sweet maize are harvested before maturity (Neeteson et al. 1999). Olaniyan et al. (2004) suggested that the use of organo-mineral fertilizers reduces nitrate losses due to leaching and improves soil structure; and that the highest yield and total dry matter were attained at the highest N rate of 120 kg N ha^{-1}. Juntharapthep et al. (2007) found that fermented chicken manure was an efficient fertilizer and produced the highest yields of unhusked, husked and standard unhusked cob for sweet maize (14.25, 10.56 and 13.62 t ha^{-1}, respectively).

Many aspects of plant growth, such as plant photosynthetic activity, N concentration and protein content are affected by drought stress, which also influences nitrate reductase activity in species such as maize (Foyer et al. 1998) and winter wheat (Xu and Yu 2006). Prolonged periods of dehydration stress inhibit photosynthesis of most active mesophyll cells, suppressing metabolism and lowering water use efficiency. Effects on stomatal conductivity are as important as those on photosynthesis (Taiz and Zeiger 2002). Research on maize (Jacob and Lawlor 1992), wheat (Xu et al. 2009) and sweet maize (Xu et al. 2004; Fletcher et al. 2008) has shown that photosynthetic functions depend on many growth factors. 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.

The lack of information on sweet maize cultivation practices limits its introduction into temperate climate zones. For this reason, data obtained from pot experiments provides valuable knowledge regarding the (i) influences of different N rates, (ii) the applied form of fertilizers (i.e. organic or mineral), and (iii) of various water regimes on morphological and yield characteristics, and photosynthetic parameters of sweet maize.

MATERIAL AND METHODS

The effects of different N target values, fertilizer types and water regimes were studied on sweet maize morphological, photosynthesis and yield parameters in a greenhouse pot experiment (University Research Centre Maribor, Slovenia: 46°39´N, 15°41´E and 282 m.a.s.l.) under natural light and temperature conditions. N rates of 0 (control), 0.6 and 2.0 g N pot^{-1} were calculated similarly to Rodrigues (personal communication), as equivalent approximations of N target values: 70 and 170 kg N ha^{-1}, and control (presowing Nmin). The examined N rates (41 and 141 kg N ha^{-1}) were calculated according to the following formula: N rate (kg N ha^{-1}) = N target value – kg Nmin in the soil (i.e. 29 kg Nmin ha^{-1}). Different organic by-products (pumpkin cake from oil processing with 9 % N, and digestate from biogas production of pig manure with 1.6 % N) and mineral fertilizers (CAN – 27% ammonium nitrate NH_4NO_3, and ENTEC®26 – 26% ammonium nitrate and ammonium sulphate $(NH_4)_2SO_4$ with nitrification inhibitor (DMPP)) were applied to pots maintained at three water regimes.

A three-factor randomized block design was used. The basic block consisted of four pots (0.14 m in diameter and 0.90 m in height) and was carried out in three replications using sweet maize hybrid 'Gold cup F1' with normal sugar content '*su*'.

Top soil of sandy loam texture was collected near the greenhouse, homogenized and used to fill the pots. The chemical and physical properties of used soil were: organic matter 11.2 mg g^{-1}, P_2O_5 52.2 mg kg^{-1}, and available K_2O 233.2 mg kg^{-1}. After filling the experimental pots soil (15.8 kg per pot), with a bench mat at the bottom, were placed to the constructed skeleton of building net. The iron net supported the pots and maintained a constant distance of 30 cm between the plants.

Before sowing, Nmin was analyzed (Nmin = nitrate-N + ammonium-N = 8 mg kg^{-1}) in the soil (Scharph and Wehrmann 1975; ISO/DIS 14255 1998), and on this basis the N rate was calculated. Fertilizers were applied before sowing, mixed in the upper 0.1 m of soil in the pot. Soil Nmin was also analyzed at BBCH 75–79 growth stage (milk stage) (Zadoks et al. 1974) and samples were taken from all pots. In total, 300 pots were used. Due to technical limitations (i.e. greenhouse area) the control treatment without added N was analyzed only at the optimal water regime (2.6 pF).

Three days after filling pots, sweet maize was sown into pots (after emergence, thinning reduced the numbers to one plant per pot) and tensiometer tubes (30 cm long) were placed randomly into pots with one tensiometer per treatment (i.e. only in the first replication). After sowing, pots were subjected to the three different soil water regimes. Water regimes were controlled as by Van der Vecken et al. (2003) with tensiometers at soil matric potentials of 2.40 pF (considered as overwatered), 2.60 pF (optimal watered) and 2.80 pF (drought stress) as measured by SMS model 2500 (SDEC, France), where pF units are logarithms of hPa. At BBCH 13–14 stage, all treatments were sustained at optimal water regime (2.6 pF). The tensiometers were placed in pots for daily measurements of the pressure generated in the water column and to calculate the amount of water needed for a given water regime. Tensiometer measurements were performed daily before irrigation. The relationship between matric potential and gravimetric soil moisture content (from wilting point to field capacity) was read from the calculated desorption curve (ISO 11274 1998).

Morphological and yield parameters for all plants were determined at harvest. Measurements included (masses are all in fresh weights): cob mass, plant mass (whole plant), plant green mass (aboveground biomass), root mass, leaf mass, stem mass, broom mass, root length, cob length, cob diameter and plant height.

During the growing season, photosynthetic parameters (photosynthetic rate – A, and stomatal conductance – g_s) were monitored by gas-exchange equipment (LCpro+, ACD BioScientific Ltd, UK). Environmental conditions in the leaf chamber were set by LCpro+ equipment. Measurements were made during 10:00–14:00 h on the upper fully expanded leaf at stages BBCH 15–17 (A1 and g_s1), 65–69 (A2 and g_s2) and 75–79 (A3 and g_s3) using the method of Hirasava and Hsiao (1999). They were repeated five times at min^{-1} intervals and the mean of the five readings was taken as the measured value.

An analysis of variance (ANOVA; $P < 0.001$, $P < 0.01$ and P

< 0.05) for a factorial experiment (fertilizer × N rate × water regime) was performed using the Statgraphic® Centurion (2005) statistical package. Significant differences among treatments were determined using least significant difference (LSD) test at P < 0.05. Pearson's correlation coefficients between morphological and yield parameters, photosynthetic parameters and Nmin were calculated using SPSS 15.0 for Windows statistical package (2005). A quadratic regression was calculated only for some significant properties.

RESULTS AND DISCUSSION

Morphological characteristics

In the case of N rates, there were no significant differences in root, leaf and broom mass (Table 1). In contrast, plant mass, green mass, stem mass and plant height significantly increased as N rates were increased. There was a significant effect of N on root length, with significantly longer roots at the lower N rate of 0.6 g pot^{-1}. This indicated the possibility that plants experiencing less N in the soil develop deeper root systems. Similar results were also reported for common maize by Rhoads and Bennett (1990), who found out that crop roots took up nutrients and water from upper levels of the soil under low-water stress or non-stress conditions. Furthermore, based on the measured morphological parameters, pumpkin cake fertilizer appeared to be an acceptable substitute for the N mineral fertilizers. When ENTEC®26 fertilizer, which has a longer fertilization effect, was compared with either CAN 27 or pumpkin cake, there were no significant differences. Similarly, Guertal (2000) reported results with bell pepper where slow-release fertilizers had no consistent improvement over a soluble N source. The use of digestate in the present study resulted in significantly lower plant mass and plant height, and also in less N residues at harvest compared to the other three fertilizers. These results can be explained by the use of fresh digestate, which can lead to phytotoxic effects or to N loss by ammonia volatilization (Abdullahi et al. 2008; Fuchs et al. 2008).

Water regimes also had a significant effect on all investigated morphological parameters of sweet maize. Except for root length, there was no significant difference between overwatered and optimal water regimes in any morphological parameter. However, all parameters were significantly lower under drought stress conditions. Only root length significantly differed in all water regimes; in comparison to the optimal water regime, there were significantly longer roots in the overwatered condition, and significantly shorter roots for drought stress. In contrast, Kirtok (1998) found in common maize that frequently watered plants produced a shallow root system, whereas occasionally watered plants produced a deep root system. However, in the present study the root mass of overwatered compared to optimally watered plants was not different (Table 1).

Table 1: Effects of water supply and N fertilization on morphological parameters (cob mass–CM; plant mass–PM; plant green mass–GM; root mass–RM; leaf mass–LM; stem mass–SM; broom mass–BM; root length–RL; cob length–CL; cob diameter–CD; plant height–PH) of sweet maize (mean values per plant)

Treatments	CM (g)	PM (g)	GM (g)	RM (g)	LM (g)	SM (g)	BM (g)	RL (cm)	CL (cm)	CD (cm)	PH (cm)
Fertilizer (F)	***	**	NS	**	NS	*	***	NS	***	***	***
N rate (N)	*	**	**	NS	NS	**	NS	***	***	***	*
Water regime (W)	**	***	***	***	***	***	***	***	***	***	***
Interaction											
F×N	NS	**	***	***	**	**	*	NS	***	***	***
F×W	NS	NS	***	***	NS	***	***	***	***	***	**
N×W	*	**	**	NS	*	*	NS	NS	**	**	NS
F×N×W	NS	NS	NS	**	NS	*	*	***	*	NS	NS
Fertilizer											
Oil pumpkin cake	85.8 a	210.7 a	124.9	72.3 a	44.2	77.6 a	3.0 a	84.4	5.7 a	1.7 b	155.8 a
Digestate	21.5 b	138.9 c	117.4	58.2 b	39.3	75.3 a	2.8 ab	76.7	1.5 b	0.7 c	131.3 b
CAN 27	61.9 a	181.5 ab	119.7	51.1 b	42.9	74.1 a	2.6 b	84.2	6.6 a	2.1 ab	156.8 a
ENTEC®26	66.2 a	175.4 b	109.2	52.8 b	43.0	64.3 b	1.8 c	85.0	7.0 a	2.3 a	157.9 a
N rate (g pot^{-1})											
0.60	47.6 b	158.6 b	110.9 b	54.6	40.2	68.1 b	2.6	88.0 a	4.1 b	1.3 b	147.0 b
2.00	70.1 a	194.6 a	124.6 a	62.6	44.5	77.5 a	2.5	77.2 b	6.3 a	2.0 a	153.9 a
Water regime											
Drought stress	30.4 b	115.3 b	84.9 b	20.2 b	27.9 b	55.1 b	1.9 b	70.6 c	1.2 b	0.4 b	114.0 b
Optimal water	74.5 a	210.0 a	135.5 a	79.8 a	49.8 a	82.7 a	2.9 a	82.6 b	7.6 a	2.4 a	170.7 a
Overwatered	71.6 a	204.6 a	132.9 a	75.8 a	49.5 a	80.6 a	2.9 a	94.6 a	6.8 a	2.3 a	166.7 a

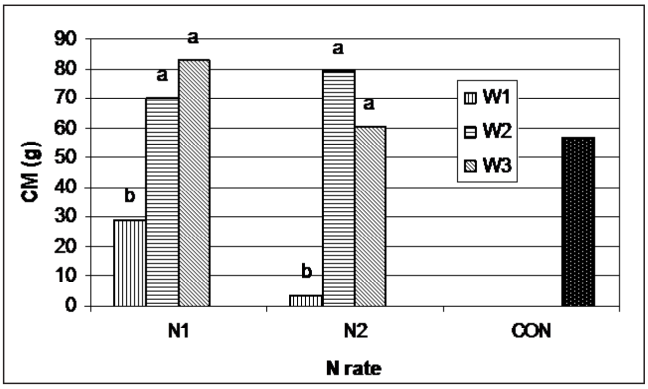
*, **, ***, NS: significant at P < 0.05, P < 0.01, P < 0.001, and not significant, respectively
a-c values within column followed by the same letter are not significantly different at P < 0.05 (LSD test).

Parameters of yield formation

There were significant differences in cob mass for the different fertilizers, N rates and water regimes (Table 1), but the only significant interaction was N rate × water regime (Figure 1). The pumpkin-cake organic fertilizer produced cobs of similar mass than those fertilized by CAN 27 and ENTEC®26. Rodrigues et al. (2010) found similar results for tall cabbage where ENTEC®26 and urea were not statistically different in dry matter yield and nitrogen use efficiency, in field and pot experiments. In the present study, the digestate resulted in significantly lower values of cob mass, length and diameter compared to the other fertilizers. A similar pattern to cob mass was also found for cob length. Treatment with ENTEC®26 resulted in significantly greater cob diameter compared to pumpkin cake and digestate.

The cob mass, length and diameter were significantly affected by different N rates and water regimes (Table 1). There was higher cob mass, length and diameter at the higher N rate (2 g pot^{-1}). Drought stress resulted in significantly lower cob mass, length and diameter in comparison to optimal and overwatered regimes; furthermore, these parameters were similar for the overwatered and optimal water conditions. Zhang and Davies (1989) reported a similar reduction in yield when crops were exposed to water stress for prolonged periods.

There was a strong positive correlation $r = 0.778$ ($P < 0.001$) between cob mass and plant mass (Table 2). The significant quadratic regression ($y = -0.014x^2 + 0.0954x - 9.95461$; $R^2 = 0.88$, $P > 0.001$) can explain the high influence of plant mass (x) on cob mass (y). These results were similar to those of Stone et al. (2001) who reported that yield of sweet maize is strongly related to biomass accumulation, especially to biomass accumulation after silking. There were moderate correlations between cob mass and root mass ($r = 0.529$, $P < 0.001$), and strong correlations between cob mass and plant height ($r = 0.775$, $P < 0.001$). Plant mass was also correlated with root mass ($r = 0.509$, $P < 0.001$) and with plant height ($r = 0.634$, $P < 0.001$).



Different letters indicate significant differences between treatments ($P < 0.05$).

Fig. 1: Interactions between examined treatments, water supply (drought stress–W1, optimal water–W2 and overwatered–W3) and N rates (N1–0.6 g pot^{-1}; N2–2 g pot^{-1}) treatments for the cob mass (CM) at sweet maize growth stage BBCH 75–79; parallel is shown control plot at optimal water regime (CON)

Table 2: Correlations (Pearson) between morphological characteristics (n=72) of sweet maize (plant mass–PM; plant green mass–GM; cob mass–CM; root mass–RM; plant height–PH; root length–RL)

Analyzed parameters	GM	CM	RM	PH	RL
PM	0.777***	0.778***	0.509***	0.634***	0.213
GM		0.617***	0.642***	0.615***	0.233*
CM			0.529***	0.775***	0.196
RM				0.562***	0.421***
PH					0.389***

* significant at 0.05, *** significant at 0.001.

Photosynthetic parameters

Photosynthetic rate (Table 3) was significantly affected by N rate (at BBCH 15–17), by water regime (at BBCH 65–67), and by fertilizer and water regime at harvest (BBCH 75–79). At BBCH 15–17, the measured photosynthetic rate was significantly higher at lower N rate (0.6 g pot^{-1}), but not at brooming and harvest. Zhao et al. (2005) reported that decreased photosynthetic rate of sorghum plants was associated with N deficiency. In comparison to the optimal water regime, there was a lower photosynthetic rate (BBCH 65–69 and 75–79) under drought stress conditions. Photosynthetic rate at BBCH 75–79 was lowest for digestate (4.0 μmol $m^{-2}s^{-1}$) and was higher for pumpkin cake (5.2 μmol $m^{-2}s^{-1}$), CAN 27 (6.5 μmol $m^{-2}s^{-1}$) and ENTEC®26 (8.5 μmol $m^{-2}s^{-1}$). Investigations of Efthimiadou et al. (2009) under field conditions, showed that photosynthetic rate (66 d after sowing) was significantly higher with application of cow manure at 240 kg N ha^{-1} compared to barley mulch and poultry manure (both at 35, 70 and 140 kg N ha^{-1}) and mineral fertilizer (240 kg N ha^{-1}). In the present study, of all investigated factors only water regime influenced the stomatal conductance at BBCH 65–67: it was significantly lower in drought stress compared to optimal conditions and also lower in the overwatered regime. Stomatal conductance was not significantly different between N rates and between fertilizer treatments. Similar results were achieved also by Efthimiadou et al. (2009) who investigated organic manures and conventional fertilizer in field conditions.

There were moderate correlations (data not shown) between stomatal conductance and photosynthetic rate at BBCH 15–17 ($r = 0.553$, $P < 0.001$) and BBCH 65–67 ($r = 0.699$, $P < 0.001$), but a weak correlation at BBCH 75–79 ($r = 0.332$, $P < 0.001$). Xu et al. (2004) also concluded that leaf stomatal opening for sweet maize was positively related to increases in photosynthetic functions and quantity of plant dry matter. The correlations between photosynthetic parameters (A1–A3 and g_s1–g_s3) and morphological characteristics were calculated (Table 4).

Correlations between photosynthetic rates and plant height (Table 4) were not strong, but increased during successive growth stages ($r = 0.166$, $r = 0.406$, $P < 0.001$, and $r = 0.495$, $P < 0.001$, respectively). Similarly, correlation strength between photosynthetic rate and plant mass, cob mass, cob diameter and cob length with growth increased.

Table 3: Effects of water supply and N fertilization on Nmin residuals in the soil at harvest, photosynthetic rate (A1–A3 at BBCH 15–17, 65–67 and 75–79, respectively) and stomatal conductance (g_s1–$3g_s1$ at BBCH 15–17, 65–67 and 75–79, respectively) of sweet maize (mean values per plant)

Treatments	Nmin	A1	A2	A3	g_s1	g_s2	g_s3
	mg kg^{-1}		μmol m^{-2}s^{-1}			mol m^{-2}s^{-1}	
Fertilizer (F)	***	NS	NS	***	NS	NS	NS
N rate (N)	***	**	NS	NS	NS	NS	NS
Water regime (W)	NS	NS	*	***	NS	*	NS
Interaction							
F×N	***	NS	*	**	NS	NS	NS
F×W	***	NS	NS	***	NS	NS	NS
N×W	***	NS	NS	NS	NS	*	NS
F×N×W	***	NS	NS	*	NS	NS	NS
Fertilizer							
Oil pumpkin cake	56 a	18.0	13.0	5.2 bc	0.12	0.10	0.07
Digestate	6 c	18.8	12.7	4.0 c	0.14	0.10	0.06
CAN 27	49 ab	19.2	15.6	6.5 b	0.13	0.10	0.08
ENTEC®26	43 b	19.4	11.4	8.5 a	0.14	0.09	0.11
N rate (g pot^{-1})							
0.60	17 b	20.2 a	13.8	5.8	0.14	0.10	0.07
2.00	59 a	17.5 b	12.5	6.2	0.13	0.09	0.08
Water regime							
Drought stress	38	17.6	10.1 b	3.8 b	0.12	0.08 b	0.07
Optimal water	37	19.1	15.7 a	7.6 a	0.13	0.12 a	0.09
Overwatered	41	19.8	13.7 ab	6.6 a	0.15	0.10 ab	0.08

*, **, ***, NS: significant at P < 0.05, P < 0.01, P < 0.001, and not significant, respectively
a-c values within column followed by the same letter are not significantly different at P < 0.05 (LSD test).

Table 4: Correlations (Pearson) between photosynthetic parameters (A1–A3 and g_s1–3 at BBCH 15–17, 65–67 and 75–79, respectively) and morphological characteristics, n=72

Analyzed parameters	PH	PM	GM	CM	CD	CL
gs1	0.270*	-0.006	0.083	0.038	0.072	0.064
A1	0.166	0.087	0.258*	0.090	0.133	0.105
gs2	0.356**	0.163	0.209	0.271*	0.263*	0.266*
A2	0.406***	0.256*	0.304**	0.404***	0.362**	0.429**
gs3	0.171	0.124	0.060	0.198	0.238*	0.238*
A3	0.495***	0.387**	0.202	0.589***	0.630***	0.649***

* , **, *** significant at the 0.05, 0.01, 0.001, respectively.

Only correlations between green mass (plant mass without cob) and photosynthetic rate at harvest were lower than at brooming stage. Correlations between stomatal conductance and morphological characteristics were weak; but the values increased to brooming growth stage and then declined by harvest.

Nmin at harvest

Residual Nmin in soil varied significantly with fertilizers and N rate; as well as with interactions of fertilizer × N rate, fertilizer × water regime, N rate × water regime, and fertilizer × N rate × water regime (Table 3). Residual Nmin values were significantly higher at higher N rates.

The digestate resulted in the lowest Nmin residuals (6 mg N kg^{-1}) at harvest (BBCH 75–79), and can be explained by N immobilization risk (Fuchs et al. 2008). Schievano et al. (2009) explained that immobilization of N in the soil may occur with the use of not-fully matured digestates.

There was significantly higher residual soil Nmin following fertilization using pumpkin cake, CAN 27 and ENTEC®26 (56, 49 and 43 mg N kg^{-1}, respectively); the corresponding converted values were approximately (using 1200 kg m^{-3} specific mass of the soil) 205, 179 and 154 kg N ha^{-1}. High residual values imply potential for groundwater pollution. Additionally, it is important to account for higher temperatures in the greenhouse compared to field conditions, which can increase mineralization processes in the soil. A laboratory leaching study (Huett and Gogel 2000) showed that controlled-release fertilizers at higher temperatures (30–40°C) had an N-release increased and period was shorter. But, this results lead to more clearly picture in case of interaction fertilizer × N rate (Figure 2). The mineral fertilizers at a higher N rate (2 g pot^{-1}) resulted in higher Nmin residuals compared to the lower N rate (0.6 g pot^{-1}). Especially high Nmin residuals were measured after CAN 27 application in comparison to pumpkin cake and digestate. In general, in the case of mineral fertilizers the lower N rate (0.6 g pot^{-1}) resulted in environmentally acceptable Nmin residuals (in accordance with legislation); and also the use of digestate at both N rates resulted in low Nmin residuals (5 and 6 mg N kg^{-1}). Based on a pot and field study with tall cabbage and controlled-release fertilizers, Rodrigues et al. (2010) found that ENTEC®26 was not a fertilizer that prevented N from leaching during winter conditions. Furthermore, in our case no significant differences were observed when water regimes were analyzed.

CONCLUSIONS

The by-product of pumpkin cake as an organic fertilizer had comparable effects on growth (i.e. morphological parameters) and yield parameters (cob mass, length and diameter) of sweet maize as the mineral fertilizers. ENTEC26 as a slow-release N fertilizer showed no advantage for sweet maize in any observed parameter (morphological, yield and photosynthetic parameters) in comparison to pumpkin cake or CAN 27. Fertilizing with a lower N rate (0.6 g pot^{-1}) resulted in significantly lower values of plant mass, cob mass, green mass, stem mass, cob length, cob diameter and plant height, compared to the higher N rate (2 g pot^{-1}); however, there were high soil Nmin residuals at the highest N rate (59 mg N kg^{-1}). There were similarly high Nmin residuals for all investigated fertilizers (56, 49 and 43 mg N kg^{-1}), except for pig manure digestate (6 mg N kg^{-1}). In addition, it is important to account for the higher temperatures in the greenhouse than in field conditions, since they can increase mineralization processes in soil. Furthermore, drought stress was associated with significantly lower values for all measured morphological characteristics in comparison to the optimal and overwatered regimes; however, soil Nmin residuals were not significantly different. The optimal watered regime of 2.6 pF matric potential was confirmed as an appropriate water regime, since the same or significantly higher morphological, photosynthetic or yield parameters were achieved compared to overwatered (2.4 pF) and drought stress (2.8 pF) conditions. Photosynthetic rate was significantly lower at brooming and at harvest under drought stress conditions, in comparison to the optimal and overwatered regimes. Moreover, correlations between photosynthetic rate and yield parameters were weak to moderate, but increased during successive growth stages. This study contributes results and offers opportunities for wider investigations in the field, especially for temperate climates, considering the lack of available sweet maize research results.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of national projects CRP V4-0472 (Sweet maize – development of new, economic and environmentally acceptable products) and V4-0104 (Organic Vegetable Production) conducted by the Government of the Republic of Slovenia, Ministry of Agriculture, Forestry and Food.

REFERENCES

1. Abdullahi YA, Akunna AC, White NA, Hallett PD, Wheatley R. Investigating the effects of anaerobic and aerobic post-treatment on quality and stability of organic fraction of municipal solid waste as soil amendment. Bioresour. Technol. 2008;99: 8631-8636.
2. Bavec F, Bavec M. Effects of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars (FAO 100-400). Eur. J. Agron. 2002;16:151-159.
3. Efthimiadou A, Bilalis D, Karkanis A, Froud-Williams B, Eleftherochorinos I. Effects of cultural system (organic and conventional) on growth, photosynthesis and yield components of sweet corn (Zea mays L.) under semi-arid environment. Notulae Botulae Botanicae Horti Agrobotanici Cluj-Napoca. 2009;37:104-111.
4. Fletcher AL, Moot DJ, Stone PJ. Radiation use efficiency and leaf photosynthesis of sweet corn in response to phosphorus in a cool temperate environment. Eur. J. Agron. 2008;29:88-93.
5. Foyer CH, Valadier MH, Migge A, Becker TW. Drought-induced effects on nitrate reductase activity and mRNA and on the coordination of nitrogen and carbon metabolism in maize leaves. Plant Physiol. 1998;117:283-292.
6. Fuchs JG, Baier U, Berner A, Mayer J, Schleis K. Effects of digestate on the environment and on plant production – results of a research project. ECN/ORBIT e.V. Workshop 2008. ″The future of Anaerobic digestion of Organic Waste in Europe″. Nürnberg, 2008; Pres. nr. 19.
7. Ghorpade VM, Hanna MA, Jadhav SJ. Sweet corn. In: Salunkhe DK, Kadam SS. Handbook of Vegetable Science and Technology; Production, Composition, Storage and Processing. Marcel Dekker, Inc., New York, USA, 1998: 609 - 647.
8. Guertal EA. Preplant slow-release nitrogen fertilizers produce similar bell pepper yields as split applications of soluble fertilizer. Agron. J. 2000;92: 388–393.
9. Hirasawa T, Hsiao TC. Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field. Field Crops Res. 1990;62:53-62.
10. Huett DO, Gogel BJ. Longevities and nitrogen, phosphorus, and potassium release patterns of polymer-coated controlled-release fertilizers at 30°C and 40°C. Commun. Soil Sci. Plan. 2000;31:959-973.
11. ISO/DIS 14255. International Organisation for Standardisation (ISO), ISO/DIS 14225, Soil quality – determination of soluble nitrogen fractions, Geneva, 1998.
12. ISO 11274. International Organisation for Standardisation 11274, Soil quality determination of the water retention characteristic – Laboratory methods 1998 (E), Geneva, 1998.
13. Jacob J, Lawlor D. Dependence of photosynthesis of sunflower and maize leaves on phosphate supply, ribulose-1,5-bisphosphate carboxylase/oxygenase activity, and ribulose-1,5-bisphosphate pool size. Plant Physiol.1992;98:801-807.

14. Juntharathep P, Suanphairoch S, Klaocheed S, Wongvarodom V. Effects of fertilizer types on sweet corn in organic production systems. In: Proceedings of the 45th Kasetsart University Annual Conference, Bangkok, Thailand, 2007:647-654.
15. Kirtok Y. Corn production and use. Kocaoluk, Istanbul, TR, 1998.
16. Moser SB, Feil B, Jampatong S, Stamp P. Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. Agr. Water Manage. 2006;81:41-58.
17. Neeteson JJ, Booij R, Withmore AP. A Review on Sustainable Nitrogen Management in Intensive Vegetable Production Systems. ISHS Acta Horticulturae, 506: International Workshop on Ecological Aspects of Vegetable Fertilization in Integrated Crop Production. Acta Hortic. 1999;1:17-26.
18. Olaniyan AB, Akintoye HA, Balogun MA. Effect of different sources and rates of nitrogen fertilizer on growth and yield of sweet corn. National Horticultural Research Institute, Vegetable Production, Nigeria [online], 2004. date: 16/June/2009 (website:http://tropentag.de/2004/abstracts/full/146.pdf)
19. Öktem A, Simsek M, Öktem AG. Deficit irrigation effects on sweet corn (Zea mays saccharata Sturt) with drip irrigation system in a semi-arid region I. water-yield relationship. Agric. Water Manage. 2003;61:63-74.
20. Ramadoss M, Birch CJ, Carberry PS, Robertson M. Water and high temperature stress effects on maize production. In: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia. [online], 2004. date: 10/December/2008 (website: http://cropscience.org.au.)
21. Rhoads FM, Bennett JM. Corn. In: Stewart BA, Nielsen DR (eds.), Irrigation of agricultural crops. ASAE Agronomy Monograph 30, Madison, WI, 1990:569-596.
22. Rodrigues MA, Santos H, Ruivo S, Arrobas M. Slow-release N fertilizers are not an alternative to urea for fertilization of autumn-grown tall cabbage. Eur. J. Agron. 2010;32:137-143.
23. Sari N, Yýldýz D, Abak K. Effects of sowing times on yield and some agronomic characteristics of sweet corn in the GAP area Turkey. Acta Hort. 2000;533:307-313.
24. Scharph HC, Whermann J. Die Bedeutung des Mineralstickstoffvorrates des Bodens zu Vegetationsbeginn für die N-Düngung zu Winterweizen. Landwirt. Forsch. 1975;32:100-114.
25. Schievano A, Adani F, Tambone F, D´Imporzano G, Scaglia B, Genevini PL. What is the digestate? Ricicla Group, University of Milano, Faculty of Agricultural Sciences, [online], 2009. date: 10/November/2009 (website: http://users.unimi.it/ricicla/)
26. Silgram M, Shepherd MA. The effects of cultivation on soil nitrogen mineralization. Adv. Agron. 1999;65:267-311.
27. SPSS for Windows. Standard Version (Release 15.0) SPSS, Inc., 2005.
28. Statgraphics® (Release Centurion XV) StatPoint, Inc., 2005.
29. Stone PJ, Wilson DR, Reid JB, Gillespie RN. Water deficit effects on sweet corn. I. Water use, radiation use efficiency, growth, and yield. Aust. J. Agric. Res. 2001;52:103-113.
30. Taiz L, Zeiger E. Plant Physiology. Sunderland, Sinauer Associates Inc., Sunderland, USA, 2002.
31. Van der Vecken L, Michels P, Feyen J, Benoit F. Optimization of the water application in greenhouse tomatoes by introducing a tensiometer-controlled drip irrigation system. Sci. Hortic. 2003;18:9-23.
32. Xu ZZ, Yu ZW. Nitrogen metabolism in flag leaf and grain of wheat in response to irrigation regimes. J. Plant Nutr. Soil Sci. 2006:169;118-126.
33. Xu HL, Quin F, Du F, Xu R, Xu Q, Tian C, Li F, Wang F. Photosynthesis in Different parts of a wheat plant. J. Food Agric. and Environ. 2009;7: 399-404.
34. Xu HL, Wang JH, Xu RY, Zhao AH. Leaf turgor potential, plant growth and photosynthesis in organically fertilized sweet corn. Pedosphere 2004;14:165-170.
35. Zadoks JC, Chang TT, Konzak CF. A decimal code for the growth stages of cereals. Weed Res. 1974;14:415-421.
36. Zhao D, Reddy K R, Kakani VG, Reddy VR. Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. Eur. J. Agron. 2005;22:391-403.
37. Zhang J, Davies WJ. Changes in the concentration of ABA in xylem as a function of chancing soil water status will account for changes in leaf conductance. Plant Cell Environ. 1989;13:277-285.

Rast in pridelek sladke koruze v odvisnosti od organskih in mineralnih dušikovih gnojil, odmerkov dušika in oskrbe z vodo

IZVLEČEK

Sladka koruza je v evropskih območjih z zmernim podnebjem premalo pridelovana zelenjadnica, njena poraba pa narašča. Za boljše razumevanje načinov oskrbe sladke koruze, je namen lončnega poskusa ovrednotiti vpliv različnih vodnih režimov in odmerkov dušika (N) izračunanih iz ciljnih vrednosti. N v odmerkih 0 (kontrola), 0,6 in 2 g N lonec^{-1} je bil dodan v obliki organskih ostankov – bučne pogače in digestat iz prašičje gnojevke, ter mineralnih gnojil – CAN 27 in ENTEC®26. Obravnavanja oskrbe z vodo so temeljila na izmerjenih talnih matričnih potencialih: 2,8 pF (sušni stres), 2,6 pF (optimalna preskrbljenost z vodo) in 2,4 pF (prekomerna oskrbljenost tal z vodo). V primerjavi z mineralnimi gnojili, so se bučne pogače izkazale za enako učinkovite glede na izmerjeno višino rastlin (155,8 cm), maso storža (85,8 g), zeleno maso (124,9 g) in maso listov na rastlino (44,2 g), oziroma celo kot boljše gnojilo glede na izmerjeno maso korenin (72,3 g) in metlic na rastlino (3,0 g). Parametri pridelka, kot masa (70,1 g), dolžina (6,3 cm) in premer storža (2,0 cm), kakor tudi ostanki mineralnega dušika (59 mg N kg^{-1}) so bili značilno višji pri gnojenju z najvišjim odmerkom N. Statistično nižje vrednosti vrednotenih morfoloških in parametrov fotosintetske aktivnosti (merjeno ob metličenju in spravilu) so bile povezane s sušnim stresom. Matrični potencial 2,6 pF se je izkazal kot najustreznejši za rast sladke koruze.