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PRODUCTIVITY OF SWEET MAIZE (*ZEA MAYS* L. *SACCHARATA*) AND NITROGEN SUPPLY AFFECTED BY CULTIVATION SYSTEMS IN NON TYPICAL MAIZE CLIMATE

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Abstract

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Cultivation system is a key factor in sweet maize production, especially for introduction of this underutilized vegetable into non typical - short season common maize environment (to FAO 400 group). The aim of three-year field experiment (north-eastern Slovenia, loamy sand soil) was to define the effects of cultivation systems – hoeing frequency (1, 2, 3, 4 and 6 times) during the vegetation period and mulches (polyethylene black foil, wheat straw and hand cutting) – on soil mineral nitrogen (N_{min}) and maize nitrogen use efficiency (NUE), growth and yield parameters. Higher hoeing frequencies significantly increased total yield (2.543 to 14.900 t/ha) and marketable fresh ear yield without husks (2.003 to 11.637 t/ha), as well as morphological parameters (plant mass, plant length, green mass, cob mass with husks, cob mass without husks, cob diameter, cob length and stem diameter; but not cob ratio). Polyethylene black foil mulch had significantly higher or equal effects on yield, growth parameters, NUE and soil N_{min} as high hoeing frequencies. These results indicate opportunities for organic production of sweet maize even under European temperate climatic conditions.

Key words: sweet maize; hoeing; mulch; N_{min}; growth; yield

Introduction

Sweet maize (*Zea mays* L. *saccharata* Sturt.) is an underutilized vegetable for production in Slovenia, because of non-typical climate (Fekonja et al., 2012) where even in common maize is possible to grow only FAO 100-400 groups (Bavec and Bavec, 2001, 2002), similar to Austrian, Germany, and other European climates. The use of sweet maize in Europe for human consumption has increased, consequently increasing imports from USA, for example in Germany, Austria and the Czech Republic from 842 000, 145 000 and 18 000 t/year in the year 2000 up to 1 730 000, 1 012 000 and 304 000 t/year in 2007, respectively (USDA, 2010). The total area of sweet maize in the European (20 percent of world production, mainly conventional production in France and Hungary, lack of organic sweet corn in EU market) warmer climates is 73 600 ha (van der Westen, 2008).

In the temperate European countries sweet maize is produced on a very small scale mainly by the gardeners and for such climates there is also a lack of research data. In this climate, additional to use only early growth cultivars (Rangarajan et al., 2000; Garcia et al., 2009), different factors such as plant populations (Simic et al., 2012), cultivation systems and plant nutrition (Rangarajan et al., 2000; Akman, 2002) have specific effects on growth performance and yield. The influence of cultivation systems (like tillage, hoeing) on yield can be ascribed to the fact that soil loosening breaks the soil crust and capillaries, preventing water evaporation in warm and dry lands, and changes water infiltration in the soil (Leblanc and Cloutier, 2001; Cloutier et al., 2007). Cultivation systems also affect oxidative processes, which typically promotes good aeration and rapid decomposition of soil organic matter, leading to increases of mineral nitrogen (N_{min}) in the soil (Silgram and Shepherd, 1999). This is especially important in organic farming system where organic fertilizers, including cultivation practices, support plant nutrition and improves the physical, chemical and biological conditions of the soil (Bavec and Bavec, 2007).

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Plastic mulches are used at planting as a simple, cost-effective, weed-managing, and effective soil-warming and season-extending technique that ultimately improves stand establishment and hastens maturity (Kwabiah, 2004). Plants growing under plastic mulch are more uniform since they are protected against cold temperatures and damage caused by insects, birds and rodents. The plastic mulch or plastic film acts similarly to a glasshouse by capturing and retaining daytime solar radiation and reducing heat loss at night, producing a mini-greenhouse effect (Kwabiah, 2004; Taber, 2008; Bu et al., 2013). Altier (1992) reported that intercropped sweet maize production with white clover living mulch was comparable to conventional intercropping, but only when adequate machinery for weed control was available. Davis (2005) ascertained that living mulch had a cooling effect on the soil during spring and so may not be appropriate for sweet maize production under temperate climate conditions.

Living mulch systems (Maynard, 2002; Miura and Watanabe, 2002; Davis, 2005; Turgot et al., 2005; Bhardwaj, 2007), cover crops (Lawson et al., 2012) and different forms of mechanical weeding (Krzic et al., 2001) are also effective in controlling weeds and nitrogen (N) dynamics of the soil/crop system, in the case of sweet maize due to the greater oxidation of soil organic matter upon disturbance (Silgram and Shepherd, 1999). Szymanek et al. (2005) reported that mechanical methods of weed control cause soil loosening, which had a positive effect on plant development, as sweet maize is sensitive to soil crusting. Hassink (1992) found that soil crusting is most noticeable for clay soils, where a higher degree of physical protection is afforded by aggregates, due to the presence of organic matter (until overcome by tillage). Mechanical weeding requires no less than two weedings: one to cultivate both over the corn row and between rows at the beginning of the season; and one between rows later in the season, when the crop is more developed (Leblanc and Cloutier, 2001).

However, sweet maize is more susceptible to damage caused by intra-row cultivation than common maize (Colquhoun et al., 1999). A rotary hoe, which covers a large area in a short time, can be used during early growth stages without damaging the crop or reducing yield (Leblanc et al., 2006). Intertillage should be shallow, maintaining a distance of 0.1 m from plants to avoid damaging their root systems (Szymanek et al., 2005). Soil loosening and weeding can be applied and repeated until the plants cover the inter-row space. Böhrnsen (1993) reported an increase of nitrate-N in the surface soil at 0.1–0.2 m depth after weeding (4 and 18 days), when three types of harrow and tined weeders were used. Increased levels of N were most noticeable after intra-row hoeing (but still only 4.5 kg/ha nitrate-N). Generally, crop damage from intra-row hoeing can be avoided by careful selection of cultivation tools (Welsh et al., 2002).

Often large amounts of residual N remain in soil after harvesting of crops, especially vegetables (Neeteson et al., 1999; Evanylo et al., 2008). Application of the recommended rates for field vegetables may take into account amounts of residual soil N_{min} (Silgram and Shepherd, 1999), especially if crops/vegetables are harvested before maturity, as is the case of sweet maize. It could have a negative environmental impact (Neeteson et al., 1999) and also bad influence on yield quality of forage maize (Svečnjak et al., 2007). For better nitrogen management also the CERES-Maize model is able to simulate sweet corn production under different management conditions (irrigation, nitrogen levels) sufficiently to allow exploration of tradeoffs between crop yield and nitrogen leaching for sweet corn production in Florida (He et al., 2011). But investigation on nitrogen use efficiency were lately conducted to investigate differences among different cultivars in pop corn (Muntim et al., 2013) and mostly in maize at high and low nitrogen input (Haegele et al., 2013; He et al., 2013; de Oliviera et al., 2013).

The aim of this study was to investigate the effects of (i) different hoeing intensities during the growing period and (ii) various mulching systems on N mineralization, N use efficiency, morphological parameters and yield characteristics of sweet maize. This contribution will support environmental friendly and organic production of sweet maize under non typical growing conditions of maize (to FAO 400 group), i.e. in the regions without research and established production.

Material and Methods

The field experiment was conducted in sweet maize '*su*' hybrid Gold Cup F1 according to the organic farming rules (EC 834/2007) at the University Research Centre Maribor in Slovenia (46°39´N, 15°41´E and 282 m a.s.l) from years 2005 to 2008. A randomized block design with four replications was used. Treatments were: control (without hoeing and without cutting weeds; hand cutting of weeds; hoeing once (H1), twice (H2), three (H3), four (H4) and six times (H5) in a season (Table 1); treatment with polyethylene black foil; and treatment with straw mulch. Each experimental plot had an area of 19.6 m^2. Plant density was eight plants per m^2, the distance between rows was 0.7 m, and the distance between plants within rows was 0.15 m. The preceding crop was clover. The BBCH-scale (Zadoks et al., 1974) was used to score growth stages.

The soil was sandy loam with 2.2% of organic matter. Fertilization was done on the basis of Al-analyses (Table 2) of the soil (KCl containing 60% K_2O and 33% P_2O_5). Before sowing, analysis of mineral N (N_{min}) in the soil layer of 0 – 0.9 m depth (Scharp and Wehrmann, 1975; ISO/DIS 14255, 1998) was also done. Samples were taken three times per season at BBCH 15 – 17 growth stage (when 5 – 7 leaves had developed); at BBCH 65 – 67 (brooming); and at BBCH 75 – 79 growth stages (milk stage). When the first samples were taken, treatments were hoed 1 – 3 times (Table 1). After the second N_{min} sampling (BBCH 65 – 67), plots were hoed up to five times. With regard to the results of N_{min} analysis before sowing, plots were fertilized with an organic N fertilizer Biosol (N - 8% - up to the target value of 200 kg N/ha, as is recommended for sweet maize in Slovenia (IPZ-TN, 2009).

Sowing dates were 25 May 2005, 26 April 2007 and 6 May 2008. The different sowing dates were due to weather conditions. The black polyethylene black foil and straw mulches were placed before the plants emerged. At BBCH 12–13, plants were thinned to one plant per 0.15 m in a row. In spring 2005 there was a long rainy period. Hoeing on plots was carried out in accordance with the experimental plan (Table 1).

The total yield (cobs with husks) and marketable yield (cobs without husks) were harvested at BBCH 75 – 79, from middle rows of plots. Morphological parameters of 10 plants per plot were analyzed in each replication. N uptake of marketable yield (from husked cobs) was also analyzed (five ears per plot). Cob N content was determined by the Kjehldahl method with a half-automatic Kjel-Foss analyzer (ISO 5983-1, 2005). The measured fresh cob and plant characteristics of sweet maize were: cob mass with husks, cob mass without husks, cob ratio – the ratio of cob to husk, cob diameter, cob length, green mass – plant mass without cob, plant mass, plant height and stem diameter.

The same calculations, as used by Maidl et al. (1996) in fertilizer trials, were used to obtain maize N use efficiency (NUE) affected by cultivation systems. NUE was calculated for all treatments of cultivation systems by the following steps:

- NUEy = [(dry matter marketable yield in treatment of cultivation system) – (dry matter marketable yield in control treatment)] × (N content of cultivation treatment)/(N rate).
- N use efficiency affected by cultivation systems:
- NUEp = (cob N content in treatment of cultivation system minus cob N content in the control treatment) × (dry matter marketable cob yield in treatment of cultivation system)/(N rate). N rate in our case represents the same value in all treatments.
- Total N use efficiency affected by cultivation systems NUE = NUEy + NUEp. Calculations of NUE were based on values for N content in the cob (analyzed in 2005).

The experiment was conducted in north-eastern Slovenia, which has a temperate climate with cold winters and hot summers. The average yearly precipitation is 1000 mm. The

Table 1
Plan of hoeing during 2005, 2007 and 2008 seasons

Treatments	Frequency of hoeing in a season	Dates of hoeing (day.month.year)					
		22.6.2005/ 29.5.2007/ 5/27/2008	06.7.2005/ 14.6.2007/ 6/25/2008	15.7.2005/ 2.7.2007/ 7/3/2008	20.7.2005/ 9.7.2007/ 7/17/2008	27.7.2005/ 17.7.2007/ 7/26/2008	3.8.2005/ 23.7.2007/ 7/30/2008
H1	1×		×				
H2	2×	×		×			
H3	3×	×	×	×			
H4	4×	×	×	×	×		
H5	6×	×	×	×	×	×	×

H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

Table 2
Results of soil analysis from all three years and fertilizing

Year	Soil condition					Added nutrients/fertilizers		
	pH, KCl	Organic matter, %	P_2O_5, mg/100g	K_2O, mg/100g	Nmin 0-0.9 m, kg/ha	P_2O_5/F, kg/ha	K_2O/F, kg/ha	N[1], kg/ha
2005	6.8	1.90	41.9 (E)	10.7 (B)	33.6	/	230/386	166.4
2007	6.1	1.89	23.1 (C)	16.5 (B)	25.3	70/212	230/386	174.7
2008	6.0	1.89	29.5 (D)	12.7 (B)	39.8	40/121	230/386	160.2

F – Fertilizers amount; [1] - N target value (kg N/ha) = 200 kg N/ha - kg N_{min}/ha 0-0.9 m deep of soil sums of rainfall during the vegetative period (May – October) were 700 mm in 2005, 679 mm in 2007, and 480 mm in 2008; the 20-year average for 1981 – 2000 was 664 mm. The seasonal rainfall of the first two years was higher than the long-term average. Furthermore, the climatic data for 2007 showed that the rainfall in June, when sweet maize growth is most intensive, was 66 mm lower than the 20-year average (Table 3). Small hailstorms in that year should be mentioned, as they may have contributed to the decrease in yield.

An analysis of variance (ANOVA: $P < 0.001$, $P < 0.01$ and $P < 0.05$) for factorial experiments (treatment × year) was performed using the Statgraphics® Centurion XV (2005) statistical package. Significant differences among treatments were determined by using a Duncan's multiple range test at $P < 0.05$. Pearson's correlation coefficients between yield, ear and plant characteristics were calculated using the SPSS 15.0 for Windows (2005) statistical package.

Results and Discussion

Yield

The cultivation system and year showed significant effects on total and marketable ear yields ($P < 0.001$), and their interaction significantly affected sweet maize total yield ($P < 0.05$; Table 4). Significantly lower yields were observed at the control treatment in comparison to all other treatments. Similar total yields were obtained for straw mulch, hand cutting, H1 and H2 treatments; however, the highest were for PE foil and H5 treatments. In case of marketable yield there were no significant differences among polyethylene black foil and H3 – H5 treatments. The significantly lower yields for straw mulch in comparison to polyethylene black foil and H2 – H5 (only in case of marketable yield) treatments can be explained by the use of soil N during straw decomposition by microorganisms in the soil. Several authors have reported positive effects of similar mulching systems on sweet maize production (Leblanc and Cloutier, 2001; Turgot et al., 2005). Kwabiah (2004) recommended foil use for earlier and uniform yields. Different types of mechanical weeding also contribute to higher yields (Krzic et al., 2001); in our experiment, there was a positive trend with higher hoeing frequency of higher total and marketable yields. H5 differed significantly from H1 and H2 treatments in total yield; and for marketable yield H3–H5 had significantly higher yields than H1 treatment. Marketable yield was also significantly higher in polyethylene black foil and H5 treatments in comparison to hand cutting, straw mulch, H1 and H2 treatments.

Cob and plant characteristics

The year and the treatment had significant effects ($P < 0.001$) on cob characteristics (except for cob ratio), and their interaction was significant only for cob diameter, stem diameter and plant height (Tables 5 and 6). The cob ratio did not change. The control treatment gave significantly lower values of cob and plant characteristics in comparison with all other treatments, except for plant height, where there was no significant difference between hand cutting and H1 treatments. Correlations (Table 7) of total and marketable yield with cob mass with husks ($r = 0.606$ and $r = 0.598$, respectively), and cob mass without husks ($r = 0.617$ and $r = 0.634$, respectively)

Table 3
Average monthly temperatures and percipitations sums at Maribor during 2005, 2007 and 2008 growing seasons, in comparison to 20-year average (+ or -)

Growing season	May	June	July	August	September	Average Sum
2005 growing season						
Temperature, °C	16.2 (+0.8)	19.6 (+1.2)	20.7 (+0.2)	18.1 (+2.0)	15.8	18.1
Rainfall, mm	78 (-22)	89 (-37)	201 (+92)	184 (+64)	127 (+23)	679
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
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

Table 4
Effects of years and different cultivation systems on total and marketable yield of sweet maize (t/ha)

Source of variance	Total yield	Marketable yield
Year (Y)	**	***
Treatment (T)	***	***
Interaction (Y×T)	*	ns
Year		
2005	11.193 a	9.605 a
2007	9.569 b	7.235 b
2008	12.027 a	9.851 a
Treatment		
Control	2.543 f	2.003 e
Cutting weeds	9.378 de	7.673 cd
H1	9.549 de	7.951 cd
H2	11.337 cd	9.448 bc
H3	12.760 bc	10.764 ab
H4	13.182 bc	10.861 ab
H5	14.900 ab	11.637 a
Foil black	15.893 a	12.613 a
Straw mulch	8.825 d	7.119 d

*, **, *** - significant at $P<0.05$, $P< 0.01$, $P<0.001$, respectively; ns – not significant;
a–f -indicate significant diff. within each column at the $P<0.05$ according to Duncan's multiple range test;
H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

were strong and significant ($P < 0.001$). The cob and plant characteristics (Tables 4 and 5) were lower or the same in the case of straw mulch treatment compared to different hoeing frequencies. In comparison to hoeing, the effect of polyethylene black foil treatment was significant on green and plant mass or similar for the other parameters. Despite the lack of research on sweet maize hoeing frequencies, we found only one study (Welsh et al., 2002) which suggested that hoeing twice could provide significantly better reductions of weed biomass than hoeing once. There were positive strong correlations (Table 7) between plant mass and plant length, plant mass and green mass, plant length and green mass, plant mass and total yield, plant mass and marketable yield, green mass and total yield, and green mass and marketable yield.

N uptake and N use efficiency

The significant differences among cob N content, dry matter of marketable yield, cob N uptake, NUEy, NUEp and NUE for different cultivation systems in 2005 (Table 8) were found. The cob N content of sweet maize grown with polyethylene black foil and H5 treatments were significantly higher than in straw mulch and control treatment. Marketable yield in a control (861.6 kg/ha) was significantly lower than in all other treatments. There was a trend of increasing marketable yield with higher hoeing frequencies; up to 5002.2 kg/ha in H5, which was significantly higher than for H1 and H2 treatments. Cob N uptake in control treatment was significantly lower than in all other treatments. Furthermore, H5 resulted in a significantly higher value (109.6 kg N/ha) in comparison to H1, H2, straw mulch, hand cutting and control treatments. There was also a positive trend of higher cob N uptake with higher hoeing frequencies. It is important to note that with higher hoeing frequencies it was possible to gain similar or better results for N levels as for other cultivation systems. Our results are comparable with those of Beckingham (2005) where N removal by cobs was 110 kg N/ha. Furthermore, there were no significant differences in N uptake among hand cutting, straw mulch, and H1–H3 treatments.

Generally, cultivation systems had a significant effect on NUE, NUEy and NUEp. NUEy and NUEp were significantly lower for straw mulch, hand cutting, and H1 treatments compared with the highest hoeing frequency (H5). NUEy and NUE were significantly lower in H1 than in H4 and H5 treatments. There was an increasing trend in all N use efficiencies (i.e. NUEy, NUEp and NUE) with hoeing treatments, indicating that hoeing increased soil loosening and soil aeration, which accelerated mineralization processes, enhanced available N and had a clear effect on NUE. NUE was significantly higher for polyethylene black foil mulch and for higher hoeing (H3–H5) in comparison to straw mulch and hand cutting treatments. Higher temperature and humidity in soil under polyethylene foil generally leads to better mineralization processes and higher yields (Kwabiah, 2004). Similarly, the highest significant level of NUE was found also in H3–H5 hoeing treatments.

Soil mineral N dynamics

Before sowing, the soil mineral N (0 – 90 cm deep) was 33 kg N_{min}/ha, averaged across the years. At BBCH 15–17 growth stage (as an average of all treatments) there was 90 kg N_{min}/ha due to input of organic fertilizer (170 kg N/ha) before sowing, and average temperatures above 15°C which accelerated mineralization in the soil.

There were significant differences in soil mineral N between years and cultivation systems. The significantly lower N_{min} values in 2005 might be due to lower temperatures compared to the other two years. Soil mineral N values were significantly different among treatments (Table 9) at BBCH 15 – 17 and BBCH 75 – 79. At BBCH 15 – 17, N_{min} was significantly higher for PE foil than for H1, H2, H4 and control

Table 5
Effects of different cultivation systems and years on cob characteristics of sweet maize

Source of variance	CMh, g	CM, g	CR, %	CL, cm	CD, cm
Year (Y)	***	***	***	***	***
Treatment (T)	***	***	ns	***	***
Interaction (Y×T)	ns	ns	ns	ns	**
Year					
2005	290.0 b	257.2 a	0.856 a	18.9 a	4.6 b
2007	271.4 b	206.9 b	0.704 b	15.1 b	4.0 c
2008	325.1 a	264.4 a	0.802 a	20.0 a	5.1 a
Treatment					
Control	136.1 e	111.1 e	0.816	11.9 d	3.2 c
Cutting weeds	279.1 cd	231.9 cd	0.831	16.7 c	4.6 ab
H1	314.3 bcd	261.7 abc	0.833	19.1 ab	5.0 a
H2	336.0 ab	278.8 ab	0.830	19.6 a	4.8 ab
H3	313.4 bcd	257.6 bc	0.822	19.1 ab	4.7 ab
H4	332.1 abc	268.1 abc	0.807	19.3 ab	5.0 a
H5	310.8 bcd	260.2 abc	0.837	18.9 ab	4.6 ab
Foil black	371.7 a	299.3 a	0.805	20.1 a	4.8 ab
Straw mulch	266.3 d	216.7 d	0.814	17.3 bc	4.3 b

, * - significant at $P<0.01$, $P<0.001$, respectively; ns – not significant;
a–e - indicate significant differences within each column at $P<0.05$ according to Duncan's multiple range test;
CM – cob mass without husk; CMh – cob mass with husk; CR – cob ratio; CD – cob diameter; CL – cob length;
H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

Table 6
Effects of different cultivation systems and years on plant characteristics of sweet maize

Source of variance	GM, g	PM, g	PL, cm	SD, cm
Year (Y)	***	**	***	***
Treatment (T)	***	***	***	***
Interaction (Y×T)	ns	ns	**	***
Year				
2005	350.0 b	640.1 b	153.4 c	1.86 b
2007	453.1 a	712.8 a	197.8 a	2.10 a
2008	423.2 a	748.4 a	187.1 b	2.10 a
Treatment				
Control	286.8 e	398.9 d	164.4 d	1.53 c
Cutting weeds	366.3 d	640.8 c	169.8 cd	2.01 b
H1	378.9 cd	685.7 bc	172.7 d	2.07 ab
H2	447.8 b	783.8 b	185.8 a	2.08 ab
H3	424.1 bcd	737.8 bc	186.8 a	2.01 b
H4	415.6 bcd	733.5 bc	183.9 ab	2.17 a
H5	433.6 bc	740.2 bc	184.8 ab	2.09 ab
Foil black	525.1 a	897.8 a	189.9 a	2.18 a
Straw mulch	418.8 bcd	685.1 bc	176.9 bc	2.02 b

, * - significant at $P<0.01$, $P<0.001$, respectively; ns – not significant;
a–e - indicate significant differences within each line at $P<0.05$ according to Duncan's multiple range test;
PM – plant mass with cob; GM – green mass; PL – plant length; SD – stem diameter;
H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

Table 7
Pearson's correlation coefficients between morphological parameters and total (TY) and marketable yield (MY), three year average (n=120)

Analyzed parameters	SD	PM	GM	CMh	CM	CD	CL	TY	MY
PL	0.505***	0.555***	0.701**	0.312**	0.123	0.145	0.047	0.246**	0.145
SD	1	0.740***	0.704***	0.655***	0.585***	0.549***	0.503***	0.460***	0.398***
PM		1	0.926***	0.889***	0.816***	0.620***	0.693***	0.572***	0.515***
GM			1	0.676***	0.557***	0.383***	0.412***	0.433***	0.344***
CMh				1	0.945***	0.756***	0.856***	0.606***	0.598***
CM					1	0.780***	0.921***	0.617***	0.634***
CD						1	0.832***	0.432***	0.433***
CL							1	0.534***	0.577***
TY								1	0.948***

, * - significant at $P<0.01$, $P<0.001$, respectively;
SD – stem diameter; PM – plant mass; GM – green mass; CMh – cob mass with husks;
CM – cob mass without husks; CD – cob diameter; CL – cob length

Table 8
Effects of different cultivation systems on total N, N uptake, and nitrogen use efficiency affected by cultivation systems in case of marketable yield (dry matter base), in year 2005

Treatments	CM, %	N_{cob}, %	MY, kg/ha	N_{uptake}, kg N/ha	NUEc [c], %	NUEp [p], %	NUE [c + p], %
Control	26.4	1.88 bc	861.6 d	16.1 e	–	–	–
Cutting weeds	32.6	1.99 abc	2613.6 c	52.8 d	21.4 c	2.3 c	23.7 d
H1	31.7	1.99 abc	2869.1 c	56.1 d	23.4 c	3.3 c	26.7 d
H2	27.4	2.12 ab	3049.8 bc	64.7 bcd	27.9 bc	4.42bc	32.3 bcd
H3	28.2	2.01 abc	4002.8 abc	79.9 abcd	37.6 abc	4.5 bc	42.1 abcd
H4	32.8	2.09 abc	4513.3 ab	93.8 ab	45.6 ab	5.4 abc	51.0 ab
H5	28.5	2.19 a	5002.2 a	109.6 a	54.5 a	9.3 a	63.8 a
Foil black	25.7	2.24 a	3877.9 abc	86.6 abc	40.5 abc	8.9 ab	49.4 abc
Straw mulch	34.2	1.86 c	2969.9 bc	55.6 cd	23.8 c	1.9 c	25.7 d
Significance	ns	*	***	***	**	**	**
Average	29.7	2.04	3306.7	68.3	34.3	4.9	39.3

*, *** - significant at $P<0.05$, $P<0.001$, respectively; ns – not significant;
a–e - indicates significnt differences within each column at $P<0.05$ according to Duncan's multiple range test
CM - cob mass dry matter; Ncob - total N of cob; MY - dry matter marketable yield;
Nuptake – N uptake with marketable yield; NUEc – N use efficiency by marketable yield (from cob mass);
NUEp – N use efficiency of proteins in cob (marketable yield); NUE = NUEc + NUEp
H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

treatments. There was a positive trend of increasing N_{min} values at higher hoeing frequencies. Different cultivation systems (tillage and mechanical weeding) lead to increasing N concentration in the soil (Bhörnsen, 1993; Davies and Welsh, 2002). On all plots where PE foil was used, N_{min} was higher than for the other treatments at all three growth stages. This could be a result of better mineralization conditions in the soil (more humidity and warmth than in other treatments) as also found in Canadian conditions by Kwabiah (2004). At brooming stage (BBCH 65 – 67) N_{min} mostly declined to almost half of its value (except with polyethylene black foil treatment, where values did not fall so rapidly) in compari-

Table 9
N_{min} values (0-0.9 m in depth) in sweet maize production during three growth stages (BBCH 15-17, BBCH 65-69, BBCH 75-79), three-years average

Source of variance		N_{min}	
	BBCH 15–17	BBCH 65–67	BBCH 75–79
	third decade of June	end of July	end of August
Treatment (T)	*	ns	***
Year (Y)	***	***	***
Interaction (T×Y)	***	***	***
Treatment			
Control	90.1 b	45.0	34.8 c
Cutting weeds	111.6 ab	56.5	51.3 ab
H1	78.9 b	42.9	54.5 a
H2	80.0 b	42.7	36.8 c
H3	97.4 ab	46.5	31.6 c
H4	90.1 b	41.5	38.9 bc
H5	98.5 ab	52.7	39.2 bc
Foil black	128.0 a	91.6	60.8 a
Straw mulch	111.0 ab	43.4	38.0 bc
Year			
2005	72.0 b	28.2 b	16.9 c
2007	106.2 a	56.5 a	47.8 b
2008	117.0 a	69.8 a	64.1 a

*, *** - significant at $P<0.05$, $P<0.001$, respectively; ns – not significant;

a–e - indicates significant differences within each line at $P<0.05$ according to Duncan's multiple range test;

H1 - hoeing once, H2 - twice, H3 - three, H4 - four and H5 - six folds in a season

son with the previous growth stage. Soil N_{min} under the straw mulch treatment (BBCH 65 – 67) was low due to humidity and high C:N ratio in straw, which resulted in intense aerobic microorganism activity (i.e. intense straw decomposition) during summer.

The total and marketable yield of straw mulch treatment was significantly lower compared to higher hoeing frequencies and using PE foil. Mineralization potential means that N_{min} can be higher in the following year, as reported by Shepherd (1993) for use of straw manures with winter wheat. In all treatments, the average N_{min} after harvest (BBCH 75 – 79) was low (< 61 kg N/ha); this was below the permitted N_{min} residual in the soil (80 kg N/ha) in accordance with the Slovenian Technological Guidance for Integrated Vegetable Production (IPZ-TN, 2009). In general, the straw mulch, H2–H5 hoeing frequencies and the control treatments had soil N_{min} values at harvest all within the same statistical group. There were significantly higher N_{min} for hoeing frequency H1 and PE foil treatment. Higher values of N_{min} for PE foil treatment could be due to higher temperature and humidity in the soil during autumn (Kwabiah, 2004), which enhanced microorganism activity. Other studies have also shown that higher temperature and water content supports N mineralization (Cassman and Munns, 1980; Sierra, 1997; Wang et al., 2006).

Conclusion

The three years results confirmed that hoeing frequencies and mulches significantly affected plant growth, N use efficiency and N_{min} values in soil, in European temperate climate. Sweet maize can be cultivated with higher hoeing frequencies or PE foil to increase N use efficiency, and to improve yield and growth parameters. The N_{min} residue depended mainly on climatic circumstances of each year. However, at the beginning of growth (BBCH 15 – 17), frequent hoeing increased available N_{min}, and at harvest (BBCH 75–79) residual N_{min} values decreased to almost half the value (42%) compared with soil N_{min} at BBCH 15 – 17. Furthermore, NUE increased with hoeing frequencies, indicating that higher hoeing frequencies accelerated the mineralization process. These results will contribute to the introduction of sweet maize into temperate climates, especially in organic production systems.

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References

Akman, Z., 2002. Effect of tiller removing and plant density on ear yield of sweet corn (*Zea mays saccharata* Sturt). *Pakistan Journal of Biological Sciences,* **5:** 906-908.

Altier, L. S., 1992. Analysis and modelling of nitrogen cycling in a vegetable intercropping system. Ph.D., *Cornell University*, 210.

Bavec, F. and M. Bavec, 2001. Effect of maize plant double row spacing on nutrient uptake, leaf area index and yield. *Rostlinná Výroba* **47:** 135-140.

Bavec, F. and M. Bavec, 2002. Effects of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars (FAO 100-400). *European Journal of Agronomy*, ***16*:** 151-159.

Bavec, F. and M. Bavec, 2007. Organic production and use of alternative crops. *CRC/Taylor & Francis, Boca Raton*, New York, London, 241 pp.

Bhardwaj, H. L., 2007. Muskelmelon and sweet corn production with legume cover crops. *Hortscience,* **41:** 1222-1225.

Böhrnsen, A. 1993. Several years' results about mechanical weeding in cereals. Proccedings of International IFOAM Conference, Dijon 5-9 July 1993, 93-99.

Bu, L., L. Zhu, J. Liu, S. Luo, X. Chen and S. Li, 2013. Source–Sink Capacity Responsible for Higher Maize Yield with Removal of Plastic Film, *Agronomy Journal*, **105:** 591-598.

Cassman, K. G. and D. N. Munns, 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. *Soil Science Society of America Journal,* **44:** 1233-1237.

Cloutier, D. C., R. Y. van der Weide, A. Peruzzi and M. L. Leblanc, 2007. Mechanical weed management. In: M. K. Upadhyaya and R. E. Blackshaw, (Eds.) Non-Chemical Weed Management Principles, Concepts and Technology, *CABI Head Office*, Oxfordshire, Cambridge USA, p. 111-134.

Colquhoun, J. B., R. R. Bellinder and J. J. Kirkwyland, 1999. Efficacy of mechanical cultivation with and without herbicides in broccoli (*Brassica oleracea*), snap bean (*Phaseolus vulgaris*) and sweet corn (*Zea mays*). *Weed Technology*, **13:** 244-252.

Davies, D. H. K. and J. P. Welsh, 2002. Weed control in organic cereals and pulses. Organic e-prints.
http://orgprints.org/8162/01/5.pdf (Accessed 30.6.2013)

Davis, J. M., 2005. Organic sweet corn production. *North Carolina State University.* 12/97 HIL–50.
http://www.ces.ncsu.edu/depts/hort/hil/hil-50.html (Accessed 30.05.2013)

Evanylo, G., C. Sherony, J. Spargo, D. Starner, M. Brosius and K. Haering, 2008. Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. *Agriculture, Ecosystems & Environment,* **127:** 50-58.

Fekonja, M., F. Bavec, S. G. Mlakar, M. Turinek, M. Jakop and M. Bavec, 2012. Growth performance of sweet maize under non-typical maize growing conditions. *Biological Agriculture and Horticulture*, **27:**147-164.

Garcia y Garcia, A., L. C. Guera and G. Hoogenboom, 2009. Impact of planting date and hybrid on early growth of sweet corn. *Agronomy Journal*, **101:** 193-200.

Haegele, J. W., K. A. Cook, D. M. Nichols and F. E. Below, 2013. Changes in nitrogen use traits associated with genetic improvement for grain yield of maize hybrids released in different decades. *Crop Science*, **53**: 1256-1268.

Hassink, J., 1992. Effects of soil texture and structure on carbon and nitrogen mineralization in grassland soil. *Biology and Fertility of Soils,* **14:** 126-134.

He, J., M. D. Dukes, G. J. Hochmuth, J. W. Jones and W. D. Graham, 2011. Evaluation of sweet corn yield and nitrogen leaching with CERES-Maize considering input parameter uncertainties. *Transaction of the ASABE* **54**: 1257-1268.

He, P., Z. Sha, D. Yao, S. Xing and W. Zhou, 2013. Effect of nitrogen management on productivity, nitrogen use efficiency and nitrogen balance for a wheat-maize sytem. *Journal of Plant Nutrition*, **36**: 1258-1274.

IPZ-TN, 2013. Technological guidelines for integrated vegetable production. *Ministry of Agriculture, Forestry and Food,* Republic of Slovenia, Ljubljana, 104 pp.
http://www.kmetijskizavod-celje.si/tehnoloska-navodila-za-integrirano-pridelavo-zelenjave-2013 (Accessed: 16.7.2013)

ISO, 1998. ISO/DIS 14225, Soil quality–determination of soluble nitrogen fractions, *ISO* (International Organisation for Standardisation) Geneva.

ISO, **2005.** ISO 5983-1, Animal feeding stuffs - Determination of nitrogen content and calculation of crude protein content - Part 1: Kjeldahl method, *ISO* (International Organisation for Standardisation) Geneva.

Krzic, M., **M. C. Fortin and A. A. Bomke,** 2001. Sweet corn tillage-planting systems in a humid maritime climate of British Columbia. *Journal of Sustainable Agriculture*, **19**: 25-39.

Kwabiah, A. B., 2004. Growth and yield of sweet corn cultivars in response to planting date and plastic mulch in short-season environment. *Scientia Horticulturae,* **102**: 147-166.

Lawson, A., A. M. Fortuna, C. Cogger, A. Bary and T. Stubbs, 2012. Nitrogen contribution of rye–hairy vetch cover crop mixtures to organically grown sweet corn. *Renewable Agriculture and Food Systems,* **28:** 59-69.

Leblanc, M. L. and D. C. Cloutier, 2001. Susceptibility of row-planted soybean (*Glycine max*) to the rotary hoe. *Journal of Sustainable Agriculture,* **18:** 53-61.

Leblanc, M. L., D. C. Cloutier and K. A. Stewart, 2006. Rotary hoe cultivation in sweet corn. *HortTechnology*, **16**: 583-589.

Maidl, F. X., A. Panse, J. Dennert, R. Ruser and G. Fishbeck, 1996. Effect of varied N rates and N timings on yield, N uptake and fertilizer N use efficiency of a six-roe and two-row winter barley. *European Journal of Agronomy,* **5:** 247-257.

Maynard, A. A., 2002. Leaf compost reduces fertilizer use for corn. *BioCycle,* **43:** 56-59.

Miura, S. and J. Watanabe, 2002. Growth and yield of sweet corn with legume living mulches. *Japanese Journal of Crop Science,* **71:** 36-42.

Neeteson, J. J., R. Booij and A. P. Withmore, 1999. A Review on sustainable nitrogen management in intensive vegetable production systems. *Acta Horticulturae*, **506:** 17-26.

de Oliveira, L. R., G. V. Miranda, R. O. DeLima, R. Fritsche-Neto and J. C. C. Galvao, 2013. Nitrogen uptake and utilization efficiency and enzymatic activity in maize genotypes. *Revista Ciencia Agronomica*, **44**: 614-621.

Rangarajan, A., B. Ingall and S. M. Orfanedes, 2000. Impact of plant population, nitrogen, and variety on early fresh-market sweet corn quality. *Horticultural Sciences*, **38:** 439-440.

Scharp, H. C. and J. Wehrmann, 1975. Die Bedeutung des Mineralstickstoffvorrates des Bodens zu Vegetationsbeginn für die N-Düngung zu Winterweizen. *Landwirtschaftliche Forschung,* **32:** 100-114.

Shepherd, M. A., 1993. Measurement of soil mineral nitrogen to predict the response of winter wheat to fertilizer nitrogen after applications of organic manures or after ploughed-out gras. *Journal of Agronomy Science*, **121**: 223-231.

Sierra, J., 1997. Temperature and soil moisture dependence of N mineralization in intact soil cores. *Soil Biology* & *Biochemistry*, **29:** 9-10.

Silgram, M. and M. Shepherd, 1999. The effects of cultivation on soil nitrogen mineralization. *Advances in Agronomy*, **65**: 267-311.

Simic, M., J. Srdic, J. Videnovic, Z. Dolijanovic, A. Uludag and D. Kovacevic, 2012. Sweet maize (*Zea mays* L. *saccharata*) weeds infestation, yield and yield quality affected by different crop densities. *Bulgarian Journal of Agricultural Science*, **18:** 668-674.

SPSS 15.0 for Windows, 2005. Chicago: SPSS Inc. Statgraphics® Centurion XV (2005): User Manual. *Herndon: StatPoint, Inc*., 287.

Svečnjak, Z., B. Varga, D. Grbeša, M. Pospišil and D. Mačešić, 2007. Environmental and management effects on grain quality of maize hybrids. *Cereal Research Communications* **35**: 1117-1120.

Szymanek, M., B. Dobrzański, I. Niedziółka and R. Rybczyński, 2005. Sweet corn harvest and technology physical properties and quality. Dobrzański Institute of Agrophysics, *Polish Academy of Sciences*, Lublin, Poland, 234 pp.

Taber, H. G., 2008. Sweet corn plastic mulch comparison. Iowa State Research Farm Progress Reports, Paper 521.
http://lib.dr.iastate.edu/farms_reports/521
(Accessed 30.5.2013)

Turgot, I., U. Blgl, A. Duman and E. Ackgoz, 2005. Effect of green manuring on the yield of sweet corn. *Agronomy for Sustainable Development,* **25:** 433-438.

USDA, 2010. *United States Department of Agriculture*, Economics, Statistics and Market Information System, U.S. Sweet corn statistics, World sweet corn (green maize), Import volume by country, 1961-2007.
http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1564 (Accessed: 20.7.2010)

Wang, C., S. Wan, X. Xing, L. Zhang and H. Han, 2006. Temperature and soil moisture interactively affected soil net N mineralization in temperate grassland in Northern China. *Soil Biology* & *Biochemistry*, **38**: 1101-1110.

Welsh, J. P., N. D. Tillett, M. Homeand and J. A. King, 2002. A review of knowledge: inter-row hoeing & its associated agronomy in organic cereal & pulse crops. Organic e-prints. http://orgprints.org/8162/pdf http://orgprints.org/8162/01/5.pdf [Accessed: 15.4.2013]

van der Westen, D., 2008. Hungary and France are the largest producers.
http://www.freshplaza.com/news_detail.asp?id=35118#SlideFrame_1 (Accessed: 16.7.2013)

Zadoks, J. C., T. T. Chang and C. F. Konzak, 1974. A decimal code for the growth stages of cereals. *Weed Research,* **14:** 415-421.