THE PRODUCTION TECHNOLOGIES FOR FIELD ENERGY CROPS

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Abstract: *The aim of research was to evaluate the effect of conventional, reduced tillage and no-till technologies and two fertilisation levels on a biomass production for energy use, expressed in yield of dry biomass, energy acquired and indicative price of energy per ha. During 2007-2009, the maize for silage, winter wheat and triticale was evaluated at the experimental fields of Plant Production Research Center Piešťany. The significantly highest yield of dry biomass was reached for maize for silage – 19.41 t ha*$^{-1}$ *with comparison to triticale – 15.39 t ha*$^{-1}$*. Winter wheat reached significantly the lowest yield on the average level of 14.08 t ha*$^{-1}$*. The highest amount of energy acquired (in GJ ha*$^{-1}$*) was accumulated in maize for silage with 236.99 GJ ha*$^{-1}$ *followed by triticale with 159.39 GJ ha*$^{-1}$ *and winter wheat with 152.52 GJ ha*$^{-1}$*. Composition of energy has been as follow: winter triticale – 35% composed of ethanol and 65% of straw, maize for silage 100% of biogas, winter wheat – 40% of ethanol and 60% of straw. The conventional tillage (CT) support the significantly the highest amount of energy acquired (in GJ ha*$^{-1}$*) in an average -201.15 GJ ha*$^{-1}$*, followed by minimum-tillage technology (MT) – 186.01 GJ ha*$^{-1}$ *and the lowest amount of energy acquired has been identified for non-tillage technology (NT) – 161.65 GJ ha*$^{-1}$*. The highest indicative price of energy was reached for maize for silage (€ 509.5) followed by winter triticale (€342.7) and winter wheat (€ 327.9) and for CT - € 429.48 followed by MT – € 395.75 and for NT only € 344.25. Nitrogen-based fertilisation (*N_{120}*) has guaranteed increase in indicative price of energy acquired € 415.45 compared to € 362.20 of zero-nitrogen fertilisation in an average. The best result for energy production was reached by maize for silage under conventional tillage 280.77 GJ ha*$^{-1}$ *with indicative price of 603.7 €/ha followed by triticale with 170.58 GJ ha*$^{-1}$ *and 366.7 €/ha of indicative price. Nitrogen-based fertilisation (*N_{120}*) increased the indicative price of energy about 31.2 €/ha in winter wheat up to 55.3 €/ha in maize.*

Key words**:** *maize, winter wheat, triticale, energy crops, tillage, fertilization*

INTRODUCTION

Text Facing climate change and growing energy prices, the use of bioenergy is continuously increasing in order to diminish greenhouse gas emissions, secure energy supply and create employment in rural areas (VAN STAPPEN ET AL., 2011). The average amount of crop residues available for bioenergy in EU27 was estimated at 1530 PJ/year, with a variation between 1090 and 1900 PJ/year. The average value represents about 3.2% in final energy consumption in the EU27 (SCARLAT ET AL., 2010). Biomass is expected to play an increasingly significant role in the greening of energy supply. Nevertheless, concerns are rising about the sustainability of large-scale energy crop production. Impacts must be assessed carefully before deciding whether and how this industry should be developed, and what technologies, policies and investment strategies should be pursued (BUYTAERT ET AL., 2011). Energy crops currently contribute a relatively small proportion to the total energy produced from biomass each year, but the proportion is set to grow over the next few decades (SIMS ET AL., 2006). The grain of cereals (e.g. barley, wheat, oats, maize and rye) can be used to produce ethanol and the straw can be used as a solid fuel. They can also be grown and harvested as a whole crop (grain plus straw) before the grain has ripened and used as a solid fuel or for biogas production feedstock.

Solid energy crops (e.g. whole crop maize, cardoon, sorghum, and short rotation coppice willow). These crops can be utilized whole to produce heat and electricity directly through combustion (OTEPKA AND HABAN, 2006; SIMS ET AL. 2006; OTEPKA ET AL., 2011). Cultivation of wheat, triticale and rye for energy purposes had been earlier investigated also by MIKULÍKOVÁ ET AL. (2008). From a total area of 370 thousands hectares of agricultural soil potentially devoted for non agricultural used in Slovakia, almost 100 000 hectares has been thought over as a feasible area under cultivation for energy plantation of biomass and dendromass.

The aim of the present research was to evaluate the maize for silage, winter wheat and triticale, soil cultivation technology and nitrogen fertilisation on productivity of alternative energy.

MATERIAL AND METHODS

The field experiment was carried out over period 2007-2009 on Luvi-Haplic Chernozem in Plant Production Research Center Piešťany –experimental center Borovce. The experimental site is located in the maize-barley growing region in Western Slovakia (E 17º75', N 48º58') with altitude of 167 m above MSL (Mean Sea Level). The location has continental climate with an average annual temperature of 9.09°C an average annual precipitation of 544.9 mm. The main soil type is a Luvi-Haplic Chernozem on carbonate loess with loamy to clay-loamy texture with a pH of 5.6-7.2 and medium humus content of 1.8%-2.0%, 187-234 mg kg^{-1} available P (according to Egner), 173–219 mg kg^{-1} available K (according to Schachtschabel), and 255–307 mg kg^{-1} available Mg (Mehlich II).

Evaluated factors of the field experiment:

- Factor A (crop-plant): a1 – winter triticale , a2 – maize for silage, a3 – winter wheat,
- Factor B (soil cultivation): b1 – direct sowing (no-tillage), b2 – minimum-tillage (disk tillage), b3 – conventional tillage (mouldboard ploughing);
- Factor C (nitrogen fertilisation): c1 = N_0 = unfertilized; c2 = N_{120} = 120 kg ha^{-1} of nitrogen;

The experimental design was a randomized complete block in a split-plot arrangement with two replicates of four-course crop rotation. Crops were the main plots, the soil tillage technologies were the subplots, with two level of fertilization. Common management practices for crop protection, processing and harvesting were used.

We evaluated the productivity of crops using three indicators. (i) Crop of dry matter evaluated according plant analysis. (ii) Energy production from evaluated crops calculated according amount of acquired energy: energy of maize for silage has been calculated from methane ($1m^3$ = 35.8 GJ), amount of methane was calculated from biogas production (from one kg of dry matter of maize biomass 680 dm^3 biogas is obtained), and for winter wheat and triticale from ethanol 1t = 25.121 GJ and straw 1t = 15.5 GJ (OPATH AND HORBAJ 2004; SIMS ET AL. 2006). (iii) Gain of energy was expressed in indicative price in Euro (€). Indicative price of 1 GJ of energy from biomass has been balanced at the level of € 2.15 (own calculation for 2009 year). The data were statistically evaluated by an analysis of variance using the Statgraphics plus procedure and the F-test (Fisher's protected LSD test).

RESULTS AND DISCUSSIONS

The temperature during a vegetation period (April – September) ranged from 17.05°C (year 2007) to 18.6°C (year 2009), while in 2007 the vegetation period was warm, in years 2006 and 2008 very warm and in 2009 exceptionally warm. During a winter half year (October – March), the temperature varied between 2.9°C (year 2006) and 4.7°C (year 2008). The temperature in a winter half year 2006 was standard, in years 2007 and 2008 exceptionally warm and in 2009 warm. Long-term average temperature in a period 1971–2000 was 15.6°C for a vegetation period and 2.5°C for a winter period (Table 1).

Table 1

Weather condition during evaluated period 2006-2009 in Borovce

Year period	LTA (1971-2000)	2006	2007	2008	2009	LTA (1971-2000)	2006	2007	2008	2009
	Precipitation (mm)					Temperature (°C)				
IV-IX	326.0	339.6	351.6	344.6	254.2	15.6	17.37	17.05	17.62	18.63
X-III	218.9	204.2	247.5	187.5	329.7	2.5	2.91	4.31	4.67	3.39
I-XII	544.9	543.8	599.1	532.1	583.9	9.1	10.14	10.68	11.15	11.01

All evaluated years had standard humid conditions with comparison to long-term average 544.9 mm. Precipitation during a vegetation period (April – September) ranged from 254.2 mm (year 2009) to 351.6 mm (year 2007) and standard condition were recognized. Precipitation during a winter period (October – March) ranged from 187.5 mm (year 2008) to 329.7 mm (year 2009), a precipitation amount of winter period was standard in years 2006, 2007 and 2008, but very humid in 2009.

Yield of dry biomass, energy acquired and indicative price of energy were influenced by the year, crops, tillage technology and different fertilization (Table 2). Significant interaction between year - crop, year - tillage and crop - tillage, indicates that the year conditions significantly affected all evaluated sources of variation except fertilization.

Table 2

F statistics from ANOVA for yield of dry matter, energy acquired and indicative price of energy for the years 2007-2009

Source of variability	d.f.	Yield of dry biomass [t ha^{-1}]		Energy acquired [GJ ha^{-1}]		Indicative price of energy per ha [€]	
		Sum of squares	F statistics	Sum of squares	F statistics	Sum of squares	F statistics
Year (Y)	2	867.83	58.00++	121285.33	87.36++	547458.3	66.89++
Crop (C)	2	1108.55	74.08++	316866.78	228.24++	1349239.8	164.86++
Tillage (T)	2	413.46	27.63++	56902.27	40.98++	265317.6	32.41++
Fertilization (F)	1	67.52	9.02++	22766.33	32.79++	141794.9	34.65++
Y x C	4	1346.36	44.99++	119777.60	43.13++ ++	484094.19	29.57++
Y x T	4	196.11	6.55++	316866.78	4.98++	57060.25	3.48++
C x T	4	671.23	22.43++	100277.08	36.11++	419115.60	25.60++
Residual	182	1361.57	-	126334.20	-	744757.62	-
Total	215	6264.84	-	900035.36	-	4140034.4	-

++ Significant at $P < 0.01$ probability level

Partitioning of the variance (Table 3) revealed that year evaluated crops and year conditions prevailing during specific year were the crucial factors in determination of yield of dry matter, energy acquired and indicative price of energy. Variability of yield of dry matter was explained by crops and year condition what accounted for 30.56% of the total variance and the interaction between years x crops accounted for an additional 20.8% of the total variance in yield of dry biomass. Evaluated crops were the most important factors in determining energy acquired (35.2%) and indicative price of energy (32.59%).

Yield of *crop dry biomass* is documented on the table 4. In a period 2007–2009, dry biomass crops reached a yield of 16.29 t ha^{-1} as an average of the experiment. Significant differences were observed between the years. While in 2008 yield of dry matter was 18.99 t ha^{-1}. In 2007 and 2009 yield of dry matter was only 14.19 t ha^{-1} or 15.70, respectively. Similarly the highest level of acquired energy was reached in 2008 – almost 213 GJ ha^{-1} with comparison to 155.56 GJ ha^{-1} and 179.98 GJ ha^{-1} in 2007 and 2009.

Table 3

Explain variance of components significant at the P < 0.01 probability level, components and interaction

Source of variability	Yield of dry matter [t ha^{-1}]	Energy acquired [GJ ha^{-1}]	Indicative price of energy per ha [€]
	Variance (% of total)	Variance (% of total)	Variance (% of total)
Year (Y)	13.42	13.47	13.22
Crop (C)	17.14	35.20	32.59
Tillage (T)	6.39	6.32	8.82
Fertilization (F)	1.04	2.52	3.42
Y x C	20.80	13.30	11.69
Y x T	3.03	35.20	1.37
C x T	10.38	11.14	10.12
Residual	21.06	14.03	17.98
Total	100	100	100

The significantly highest yield of dry biomass was noted for maize for silage 19.41 t ha^{-1} with comparison to triticale (15.39 t ha^{-1}). Winter wheat reached significantly the lowest yield on the average level of 14.08 t ha^{-1}.

Table 4

Average value of indicators of evaluated crops under different soil cultivation technology and fertilization level during 2007-2009

Indicator	Dry biomass [t ha^{-1}]	Energy acquired [GJ ha^{-1}]	Indicative price of energy per ha [€]
Total average of the experiment	16.29	182.97	389.83
2007	14.19 a	155.56 a	334.43 a
2008	18.99 c	213.37 c	456.26 c
2009	15.70 b	179.98 b	378.80 b
$LSD_{0.01}$	0.89	8.66	21.04
Crops			
Winter triticale	15.39 b	159.39 a	342.7 a
Maize for silage	19.41 c	236.99 b	509.5 b
Winter wheat	14.08 a	152.52 a	327.92 a
$LSD_{0.01}$	0.89	8.66	21.04
Soil tillage			
No-tillage (NT)	14.45 a	161.75 a	344.25 a
Minimum-tillage (MT)	16.64 b	186.01 b	395.75 b
Conventional tillage (CT)	17.79 c	201.15 c	429.48 c
$LSD_{0.01}$	0.89	8.66	21.04
Fertilization			
Lower level (N_0)	15.73 a	172.70 a	362.20 a
Higher level (N_{120})	16.85 b	193.23 b	415.45 b
$LSD_{0.01}$	0.73	7.07	17.17

The means followed by the same letter are not significantly different at P 0.01< probability level

According comparison of three tillage technologies the conventional tillage (CT) creates the best soil environment with significantly higher yield of dry biomass (17.79 t ha^{-1}). Significantly less yield of dry biomass was noted in minimum tillage (NT) and no till technology (NT) treatments. It is possible to perform this technology only in particular soil conditions (VILČEK AND KOVÁČ, 2011).

Crops growing for energy production have been compared as well on a basis of *energy acquired* (in GJ ha^{-1}). In a period 2007–2009 average energy of the experiment at the level of 182.97 GJ ha^{-1} was acquired. Production of acquired energy varied significantly between evaluated years with the most favourable condition in 2008. The highest amount of energy acquired (in GJ ha^{-1}) was accumulated in maize for silage with 236.99 GJ ha^{-1} followed by triticale with 159.39 GJ ha^{-1} and winter wheat with 152.52 GJ ha^{-1}. Composition of energy (Table 4) has been as follow: winter triticale – 35% composed of ethanol and 65% of straw, maize for silage 100% of biogas, winter wheat – 40% of ethanol and 60% of straw. These results are higher than energy value of the crop obtained by energy balance evaluation due to full accounting of storage energy of biomass. POSPIŠIL AND RŽONCA (2010) stated energy value of winter wheat yields in interval 96.4 – 107.6 GJ ha^{-1} and for maize in interval 149.4 – 177.6 GJ ha^{-1} by using coefficient of 17.64 GJ Mg^{-1} of dry matter of main product.

The CT support the significantly the highest amount of energy acquired (in GJ ha^{-1}) in an average -201.15 GJ ha^{-1}, followed by minimum-tillage technology (MT) – 186.01 GJ ha^{-1} and the lowest amount of energy acquired has been identified for non-tillage technology (NT) – 161.65 GJ ha^{-1}.

Nitrogen-based fertilisation (N_{120}) has supported a highly significant increase in the amount of energy acquired (in GJ ha^{-1}) on the level of 20.53 GJ ha^{-1}.

As economic indicator indicative price of acquired energy in plant biomass was calculated according € 2,15 for one GJ of acquired energy. In a period 2007–2009 indicative price of storage energy of whole crop rotation was balanced at € 389.83. The highest indicative price of energy was reached for maize for silage (€ 509.5) followed by winter triticale (€342.7) and winter wheat (€ 327.9). The highest indicative price of energy acquired was reached for CT - € 429.48 followed by MT – € 395.75 and for NT only € 344.25. Nitrogen-based fertilisation (N_{120}) has guaranteed increase in indicative price of energy acquired € 415.45 compared to € 362.20 of zero-nitrogen fertilisation in an average. For partitioning of energy calculated see table 5.

Table 5

The energy composition, calculated for different sources of energy crops [GJ ha^{-1}]

Experiment	Winter triticale			Maize for silage	Winter wheat		
	Ethanol	Straw	Total		Ethanol	Straw	Total
NTT	51.3	105.3	156.6	173.5	57.8	97.3	155.1
MTT	52.8	98.2	151.0	256.7	63.2	87.2	150.4
CTT	63.9	106.8	170.6	280.8	66.7	85.4	152.1
N_0	51.9	96.8	148.7	224.1	55.6	89.6	145.3
N_{120}	60.0	110.1	170.1	249.9	69.5	90.3	159.8

Where: average – average of the experiment, NT – no-tillage technology, MT – minimum tillage technology, CT – conventional tillage technology, N_0 – lower fertilization level, N_{120} – higher fertilization level

Average values of plant dry biomass with respect to soil cultivation technology and fertilization are in table 6. Maize for silage under CT reached 22.86 t ha^{-1} with comparison to 14.13 t ha^{-1} in NT. These results are with concordance with results received by HNÁT (2009) on eastern Slovakia with the evaluation of the same tillage treatments on yield of maize. The conventional tillage supports the significantly higher yield of grain followed by the minimum tillage and the lowest yield for no-tillage system was determined. Similarly KOTOROVÁ ET AL. (2010) found that the tillage systems decreased the yield of grain maize in order CT>MT>NT.

Table 6

Value of indicators for crops under different growing technologies in 2007-2009 in Borovce

Indicator	Dry matter	Energy acquired	Indicative price of energy per ha
	t ha^{-1}	GJ ha^{-1}	(€)
Crop x Tillage			
Triticale – NT	14.72	156.64	336.8
Triticale - MT	15.01	150.96	324.6
Triticale - CT	16.44	170.58	366.7
Maize - NT	14.13	173.51	373.0
Maize - MT	21.24	256.69	551.9
Maize - CT	22.86	280.77	603.7
Wheat - NT	14.51	155.08	333.4
Wheat - MT	13.68	150.37	323.3
Wheat - CT	14.06	152.11	327.0
Crop x Fertilization			
Triticale - N_0	14.79	148.71	319.7
Triticale - N_{120}	15.99	170.08	365.7
Maize - N_0	18.25	224.13	481.9
Maize - N_{120}	20.57	249.85	537.2
Wheat - N_0	14.16	145.27	312.3
Wheat - N_{120}	14.00	159.77	343.5
Tillage x Fertilization			
NT x N_0	13.54	183.48	394.5
NT x N_{120}	15.06	209.58	450.6
MT x N_0	15.37	211.80	455.4
MT x N_{120}	17.16	233.70	502.5
CT x N_0	17.87	246.54	530.1
CT x N_{120}	17.97	252.45	542.8

The best result for energy production was reached by maize for silage under conventional tillage 280.77 GJ ha^{-1} with indicative price of 603.7 €/ha followed by triticale with 170.58 GJ ha^{-1} and 366.7 €/ha.

Nitrogen-based fertilization (N_{120}) increased the indicative price of energy about 31.2 €/ha in winter wheat up to 55.3 €/ha in maize. UŽÍK AND ŽOFAJOVÁ (2009) also found that effect of N on grain yield of different cultivars of winter wheat was significant, but little effective on the fertile soil environment. Nutrient inputs and their efficiency on wheat yields is also important part for sustainability of the growing system and (LACKO-BARTOŠOVÁ, 2006; TÝR ET AL., 2009; LACKO-BARTOŠOVÁ AND KRISTIANSEN, 2010).

From environmental point of view we have to take into consideration also energy inputs (POSPIŠIL AND RŽONCA, 2010), environmental load from nitrogen fertilization (FAZEKAŠOVÁ ET AL., 2011) and environmental approaches (LACKO- BARTOŠOVÁ ET. AL., 1995).

CONCLUSIONS

The aim of research was to evaluate the effect of conventional, reduced tillage and no-till technologies and two fertilization levels on a biomass production for energy use, expressed in yield of dry biomass, energy acquired and indicative price of energy per ha. The significantly highest yield of dry biomass was reached for maize for silage 19.41 t ha^{-1} with comparison to triticale (15.39 t ha^{-1}). Winter wheat reached significantly the lowest yield on the average level of 14.08 t ha-1. Similarly the highest amount of energy acquired (in GJ ha^{-1}) was accumulated in maize for silage with 236.99 GJ ha^{-1} followed by triticale with 159.39 GJ ha^{-1} and winter wheat with 152.52 GJ ha^{-1}. The CT support the significantly the highest amount of energy acquired (in GJ ha-1) in an average 201.15 GJ ha^{-1}, followed by minimum-tillage technology (MT) – 186.01 GJ ha^{-1} and the lowest amount of energy acquired has been identified for non-tillage technology (NT) – 161.65 GJ ha^{-1}. The highest indicative price of energy was reached for maize for silage (€ 509.5) followed by winter triticale (€342.7) and winter wheat (€ 327.9). The highest indicative price of energy acquired was reached for CT - € 429.48 followed by MT – € 395.75 and for NT only € 344.25. Nitrogen-based fertilization (N120) has guaranteed increase in indicative price of energy acquired € 415.45 compared to € 362.20 of zero-nitrogen fertilization in an average. The best result for energy production was reached by maize for silage under conventional tillage 280.77 GJ ha^{-1} with indicative price of 603.7 €/ha followed by triticale with 170.58 GJ ha^{-1} and 366.7 €/ha of indicative price.

Nitrogen-based fertilization (N120) increased the indicative price of energy about 31.2 €/ha in winter wheat up to 55.3€/ha in maize. For bio energy purposes the energy acquired indicator is recommended.

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