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Farming systems and environmental impacts

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Abstract. Energy crop production in organic farming.
A basic principle of organic farming is to „reduce the use of non-renewable resources (e.g. fossil fuels) to a minimum". Biomass is a key resource for biogas or biofuel. The main objective of this study was to find out the species and the species mixtures which could produce a high amount of above ground biomass for energy production.
In 2007/2008 productivity of different field crops and grasses was investigated in natural, mineral fertilizer, slurry and wastewater sludge treatments. For field crops and grasses the productivity was studied in the case of pure and mixture sowings. The biomass chemical composition including heavy metals was studied.
The highest above ground biomass was obtained from experimental treatments with maize cultivars, followed by hemp cultivars fertilized with wastewater sludge. The highest yield from grasses was obtained from smooth brome grass on mineral fertilizer background which was followed by reed canary grass on sewage sludge background. The lowest yield was obtained from cocksfoot.
To avoid the damage of soil texture the wastewater as renewable nitrogen (N) resource should be used only after 3 years.

INTRODUCTION

Well-known principles of organic farming are the banning of synthetic biocides and of synthetic mineral fertilisers. Another aim of organic farming is „to use, as far as possible, renewable resources in production and processing systems and avoid pollution and waste" (Information sheet, 2005). The energy produced from energy crops (e.g. biogas) is a possibility to replace fossil fuels by renewable resources. According to the data of Roostalu et al. (2008) over 283 000 ha of land in Estonia is vacant now, and here energy crop cultivation is feasible. Silo-maize, grain cereals and grass silage are common cultivated energy crops in the world. More than 90% of modern biogas plants use maize silage as the most effective energy crop and nearly 50% use total cereal silage (Weiland, 2007). More unconventional crops like Sudan grass, sweet sorgum, sunflower and Jerusalem artichoke have shown also high gas yields, but their cultivation is rare up to now (Weiland, 2007). Energy crop production in organic farms would not be the most important branch of activity and the vacant land would be used for their cultivation. Very important is to avoid environmental pollution by inexpensive production of energy plants (e.g. weedy fields, soil pollution with heavy metals or to destroy soil texture with excessive wastewater).

In 2007/2008 the influence of different N resources (mineral N fertilizer, slurry, wastewater sludge and vetch) on the productivity of different field crops (maize and hemp) and grasses (reed canary grass, smooth bromegrass and cocksfoot) was investigated. The biomass chemical composition including heavy metals was studied. The aims for the research were (i) to find the species and the species mixtures which could be cultivated in Estonian conditions for energy biomass production; (ii) to investigate different renewable nitrogen (N) resources like wastewater sludge, slurry and vetch for energy crop cultivation; (iii) to avoid environmental pollution.

MATERIALS AND METHODS

Field trial, experimental details

Two experimental field trials were carried out in 2007/2008 at the Institute of Agricultural and Environmental Sciences of Estonian University of Life Sciences near Tartu (58° 23´N, 26° 44´E) on Stagnic Luvisol (WRB 1998 classification) soil (sandy loam surface texture, C 1,2%, and N 0,12%., pH_{KCl} 5,6).

The first trial, a field trial with energy crops, considered two factors: N treatment and different energy crop species and cultivars (Table 1).

Table 1. Trial scheme

Treatment	Species and cultivars
1. N0 – without N	1. Maize
2. N100 - mineral N fertilizer NH_4NO_3 (100 kg N ha^{-1})	Cultivar Ainergy (8 viable seeds m^{-2})
	Cultivar Crescendo (8 viable seeds m^{-2})
3. Wastewater sludge from Tartu (100 kg N ha^{-1})	2. Hemp
4. Vetch (cultivar Carolina, 60 viable seeds m^{-2})	Cultivar USO-31 (200 viable seeds m^{-2})
5. Slurry (100 kg N ha^{-1})	Cultivar Chameleon (200 viable seeds m^{-2})

Both maize cultivars were obtained from Older Group and hemp cultivars from Estplant. Seeds were sown on 20 May to a depth of 3–5 cm, with 15-cm intervals between the rows. The experiments were performed in a randomized complete block design with four replications, plot size 15 m^2. The fertilizers were applied once: the wastewater sludge and slurry were applied prior to sowing, and mineral N fertilizer (NH_4NO_3) was applied after the emergence of plants (06.06.2008). The results of chemical analyses from the wastewater sludge and slurry are presented in Table 2. According to earlier studies the 60 viable seeds of vetch were considered to be equal to 100 kg mineral N ha^{-1} (Lauk & Lauk, 2006; Lauk et al., 2007). During the vegetation period no pesticides, mechanical or manual weeding were used. Until anthesis every two weeks the height of plants was determined, and the percent of weeds m^{-2} were assessed by phenological viewings. In the flowering stage of plants the chlorophyll content in plants leaves were determined by SPAD-meter. On 11 September the above ground biomass from 4 m^2 area of each experimental plot was measured. The dry matter (DM) content in energy crops and in weed biomass was determined; the biomass yield g m^{-2} and the percentage of energy crop and weeds in above ground biomass were calculated.

In the second experiment with grasses the experiment treatments were divided based on various grass species and fertilizer application as follows:

1) grasses: reed canary grass, smooth brome grass, cocksfoot;

2) N sources: mineral fertilizer and wastewater sludge;

3) rates of N, P and K: $N_0P_0K_0$, $N_0P_{30}K_{60}$, $N_{60}P_{30}K_{30}$.

The experiment was established in June 2007.

Table 2. The chemical composition of wastewater sludge and slurry

Fertilizer	DM%	pH_{KCl}	N%	P%	K%
Sludge	18.2	6.75	5.24	1.89	0.38
Slurry	6.6	6.30	4.5	0.9	3.2

Weather conditions

The meteorological station in Eerika, near the trial field, supplied the weather data (Table 3). The temperature data did not vary remarkably year to year and the temperature data were similar to the long-term average. The amount of precipitation in 2007 was much lower than long-term average, but in 2008 the amount of precipitation was similar to long-term average. The total amount of precipitation from May to the end of September 2007 was 191 mm, for 2008, 356 mm and the long-term average was 369 mm.

Table 3. Weather conditions in 2007–2008 taken from Eerika meteorological station

Month	Middle temperature, °C		Sum of precipitation, mm		Long-term average of	
	2007	2008	2007	2008	temp., °C	precip., mm
May	12.4	10.7	82	27	11.4	57
June	15.9	14.4	44	111	15.4	77
July	16.9	16.1	55	54	17.3	81
August	18.1	15.7	11	118	16.0	94
September	6.8	9.8	9	46	10.6	60

Chemical and statistical analyses

The protein, ash, fiber, fat and lignin content were determined in maize and hemp plants after different treatments. Additionally heavy metals content from wastewater, soil and plants were determined.

The trial data were processed using correlation and variance analyses (ANOVA) and descriptive statistics. The means are presented with their standard errors (±S.E.).

RESULTS AND DISCUSSION

The highest above ground biomass in the experimental trial of energy crops (crop + weeds) was obtained from maize cultivars, which were fertilized with wastewater sludge (as an average of maize cultivars 1,110 g DM m^{-2}, followed by hemp cultivars 750 g DM m^{-2}, respectively; e.g. in the control treatment the same values were 480 and 410 g DM m^{-2}, respectively).

The N treatment influenced the maize cultivars above ground biomass formation remarkably. The above ground biomass of maize (without weeds) was relatively small in N treatments, where all N applied with fertilizer was used by plants during quite a short period (N100). In this N treatment the maize cultivars growth rate decreased at the development stage BBCH30–39 (stem elongation; Tables 4, 5). The percentage of weeds in above ground biomass was lower than 50% only in wastewater sludge and slush treatments. The high percentage of weeds in above ground biomass of N treatment N100 and N0 was caused by the slow maize growth rate after anthesis (Table 6) and thus was low competition to weeds. The positive effect of wastewater on the formation of maize above ground biomass was probably because the N became mineralised from sludge slowly and was available for plants even during late summer. The wastewater sludge utilization in Estonian weather conditions could be possible for species in which active growth occurs during the second part of summer (e.g. maize or hemp).

Table 4. Plants height (cm) of maize and hemp cultivars on different N treatments (± S.E.)

Cultivar	N treatment				
	N0	N100	wastewater sludge	vetch	slurry
Maize Ainergy	72 ± 10.7[b*]	90 ± 12.7[c]	139 ± 21.1[c]	52 ± 9.9[d]	105 ± 17.3[c]
Maize Crescendo	88 ± 14.5[b]	107 ± 12.4[bc]	171 ± 8.7[b]	89 ± 1.9[b]	133 ± 17.5[bc]
Hemp USO-31	126 ± 13.0[a]	123 ± 19.1[b]	191 ± 16.7[ab]	78 ± 6.7[c]	165 ± 27.5[ab]
Hemp Chamele	119 ± 16.3[a]	175 ± 10.0[a]	197 ± 15.9[a]	118 ± 6.0[a]	185 ± 16.1[a]

* different letters denote significant difference in column

Table 5. Above ground biomass yield (g DM m^{-2}) of maize and hemp cultivars on different N treatments (± S.E.)

Cultivar	N treatment				
	N0	N100	wastewater sludge	vetch	slurry
Maize Ainergy	157 ± 8[b*]	238 ± 12[b]	922 ± 46[a]	87 ± 4[d]	352 ± 59[b]
Maize Crescen	93 ± 17[c]	169 ± 11[c]	695 ± 45[c]	158 ± 40[c]	409 ± 65[ab]
Hemp USO-31	410 ± 52[a]	582 ± 67[a]	870 ± 86[b]	317 ± 28[b]	519 ± 57[a]
Hemp Chamele	418 ± 60[a]	664 ± 71[a]	638 ± 57[c]	421 ± 32[a]	504 ± 33[a]

* different letters denote significant difference in column

Table 6. The percentage of maize and hemp cultivars in above ground biomass yield in 2008 (± S.E.)

Cultivar	N treatment				
	N0	N100	wastewater sludge	vetch	slurry
Maize Ainergy	33 ± 7[b*]	44 ± 4[c]	76 ± 3[c]	17 ± 2[b]	59 ± 5[c]
Maize Crescendo	19 ± 3[c]	29 ± 3[d]	67 ± 4[d]	23 ± 4[b]	68 ± 7[bc]
Hemp USO-31	85 ± 6[a]	98 ± 1[a]	100 ± 0[a]	44 ± 8[a]	96 ± 4[a]
Hemp Chamele	73 ± 6[a]	81 ± 3[b]	91 ± 3[b]	50 ± 3[a]	76 ± 4[b]

* different letters denote significant difference in column

The percentage of hemp above ground biomass yield was significantly influenced by cultivar and N treatment (Table 6). The stems of hemp cultivar USO-31 were slender and plant density was higher in comparison with hemp cultivar Chameleon. The germination rate of Chameleon was 2.6 times lower in comparison with USO-31. Hemp cultivars suppressed weeds very well and hemp cultivars' percentage in above ground biomass was high. This is confirmed by other authors (Van der Werf et al., 1995a, 1995b). In the hemp and vetch mixture sowing treatments the percentage of weeds formed up to 5%.

The above ground biomasses of maize- and hemp-vetch mixes as an average of maize and hemp cultivars were statistically equal to control variants N0, respectively. SPAD-meter readings determined in the flowering stage of plants showed very low chlorophyll content in plant leaves. The availability of N by plants in mix treatments was probably too low and chlorophyll content in leaves in flowering stage correlated significantly with above ground biomass at harvest time (Fig. 1). This has been confirmed by other researchers, as well (Viil, 2008). The biological N bound by Rhizobaceae probably is not available for other plants in the first vegetation period, or the sowing rate of vetch was too high and competition between plants results in low above ground biomass (Jensen, 1986, 1996; Hauggaard-Nielsen *et al.,* 2001).

In the second experimental trial the yield of grasses depended on the grass species and N source. The reed canary grass yield was the highest on the wastewater sludge background and smooth brome grass and cocksfoot yield was the highest on the mineral N fertilizer background (Table 7).

Table 7. The above ground biomass yield (g DM m^{-2}) of grasses in November of 2008

Grass species	N treatment			
	$N_0P_0K_0$	$N_0P_{30}K_{60}$	$N_{60}P_{30}K_{60}$	wastewater sludge
Reed canary grass	510 ± 13[a*]	620 ± 117[a]	670 ± 49[b]	790 ± 121[a]
Smooth brome grass	560 ± 21[a]	610 ± 54[a]	1080 ± 110[a]	680 ± 34[a]
Cocksfoot	370 ± 7[a]	560 ± 75[a]	780 ± 46[b]	550 ± 30[a]

*different letters denote significant difference in column

The protein, ash, fiber, fat and lignin content in maize and hemp cultivars (in the field crops experiment) was not influenced significantly by N treatments. The content of heavy metals did not exceed the limited norm in wastewater and soil, the content of heavy metals in harvested plants was smaller in hemp cultivars (Tables 8, 9).

Table 8. The content of heavy metals in wastewater sludge and soil

Heavy metal	Content of heavy metals				
	in the sludge, mg kg^{-1}	in the soil of (mg kg^{-1})		with the sludge mg m^{-2}	limitid norm for 10 years average, kg ha^{-1*}
		N0 treatment,	sludge treatment		
Cd	0.38	0.08	0.07	0.684	0.15
Cr	51	11	12	91.8	4.5
Cu	99	7.1	9.1	178.2	12
Ni	19	7.4	7.6	34.2	3
Pb	18	9.3	8.8	32.4	15
Zn	360	37	36	648	30

*Resource: http://www.riigiteataja.ee

Table 9. The content of heavy metals in harvested plants of maize and hemp (as an average of cultivars)

Heavy metal	Content of heavy metals mg kg^{-1}			
	in the plants of maize cultivars		in the plants of hemp cultivars	
	in N0 treatment	in sludge treatment	in N0 treatment	in sludge treatment
Cd	0.12	0.23	<0.02	0.02
Cr	0.8	0.3	0.4	0.6
Cu	8.3	6.9	4	4.8
Ni	0.7	0.2	0.3	0.7
Pb	0.3	<0.2	0.3	0.4
Zn	31	20	9.2	14

The C:N in wastewater was 9, which is too low: the optimal ratio is 20–40, the best for plants is 25–30 (Laht, 2008). The C:N was low because of low C content in wastewater (48%); the optimal content of C in wastewater is over 50% (Laht, 2008). According to the content of N the applied quantity of wastewater sludge in the field crops experiment was 18 t DM ha^{-1}, then the quantity of N was 100 kg N ha^{-1}. The quantity of dry matter (DM) applied with wastewater to the soil was too high (admissible quantity is 5 t DM ha^{-1} only; Estonian Ministry of Environment, 2004). According to the decree of the Estonian Ministry of Environment the use of this wastewater is allowed after 3 years.

After the harvest time the soil samples were taken from the energy crops experiment. It revealed from the soil chemical analyses that the C:N ratio in wastewater sludge treatment was only 8.0, which was significantly lower in comparison with other treatments (Fig. 2). The ratio was low, because the soil C content was low. The lower C content was probably caused by intensive metabolic activity between soil and plant; or the other hand, by the variability of the soil. It would be cleared during the following years. The experiment will be repeated in the fields of the Institute of Agricultural and Environmental Sciences of Estonian University of Life Sciences.

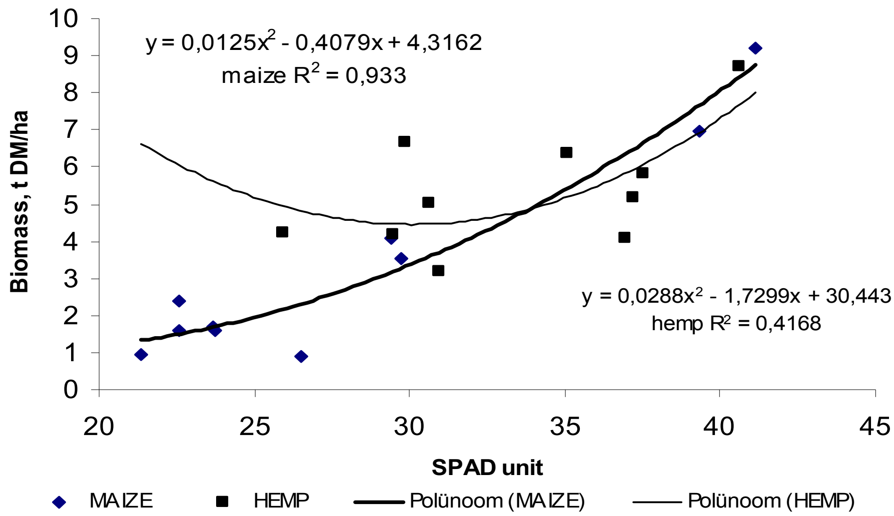

Fig. 1. The relationship between SPAD-meter data determined at anthesis and above ground biomass measured at harvest time in 2008.

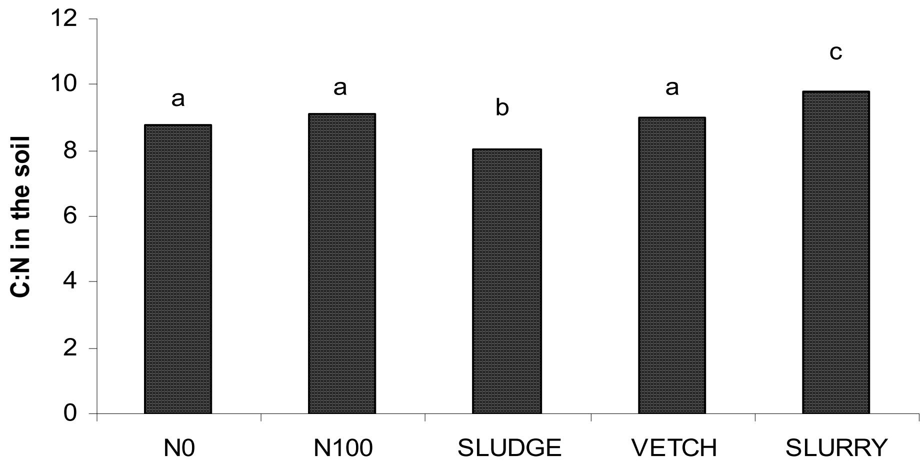

Fig. 2. The C ratio to N in the soil of different N treatments in 2008.

CONCLUSIONS

- The wastewater sludge was an effective N resource for maize and hemp above ground biomass formation.
- The effectiveness of wastewater sludge on the yield of grasses depended on the grass species. Reed canary grass yielded highest on wastewater sludge background, but smooth brome grass and cocksfoot yield was the highest on mineral N fertilizer background.

- Vetch as an N resource for energy crop biomass formation was not suitable in the first vegetation period.
- Hemp suppressed weeds very effectively..
- The quantity of heavy metals bound by plants was higher in maize cultivars.

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