University of West Hungary
Faculty of Forestry
Pál Kitaibel Doctoral School of Environmental Sciences
Bioenvironmental Sciences

Thesis of doctoral (PhD) dissertation

POSSIBILITIES OF UTILIZATION OF SUGAR BEET AND OTHER CROPS WITH HIGH CARBOHYDRATE CONTENT FOR ENERGY PRODUCTION

László Potyondi

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Doctoral School:
Kitaibel Pál Doctoral School of
Environmental Science

Program:
Bioenvironmental Science Program

Supervisor:
Prof. Dr. Marosvölgyi Béla DSc

Introduction

The energy production from plants are co-temporary with crop production. In every civilizations the dried by-products of plant production and animal husbandry was burned for heating and the feed production for livestock was served as „the plant based fuel".

Because of the reduction and limited availability of fossil fuels the importance of bioenergy was being increased in every year. Although the recent low fuel prices are not favorable for biofuel, but it may be doubtless calculated a growing market in a long period of time.
The emerging importance of environmental protection, especially the efforts for decreasing greenhouse gases (Climate Change Agreement, Paris, 2015), attracts attention for biofuel production as an element of the solution.

At the same time the bioenergy production could not detriment of the safe food supply. The food demands and market with plant production opportunities has to investigate in all cases and regions.
One of the most important aspect, that the area of plant cultivation for bioenergy production has to be as small as possible. For the best use of available areas the crops with maximum energy yields per hectare have to be choosen.

But from economic, energetic and environmental point of view alone the effort for maximum yields are non-allowable. Therefore the formation of expenditures and incomes have to be investigated, and the energy balance of crop production have to be more positive. The positive energy balance will be beneficial for economic and environmental (the energy and carbon-dioxide balance move about together) point of view, as well.

The basic selection criteria of crops of this study were the availability of the well-established and continuously developing energy positive agricultural methods and technical solutions.

Another important aspect was, that the crops between the main products have significant quantity of by-products usable for energy production.

Objectives

- Based on the data from literature analyzis the status and alteration of utilization of renewable energy in the world and European Union and the utilization of biofuel and biogas in the EU, in the Danube-region and in Hungary, too.

- To test the biogas production in batch fermentation from different varieties of silage maize, sorghum and sugar beet, and from different parts of sugar beet and Jerusalem artichoke with their processing by-products.

- After the comparison of results from batch fermentation with the data from literature to assess the energy potentials of silage maize and sugar beet on the levels of analyzed regions.

- To examine the nutrient effect of sludge from biogas production from sugar beet pressed pulp in field trials with winter wheat and corn.

Materials and methods

Examinations of biogas production:

Tested materials:

8 varieties of silage maize, sorghum and sugar beet, respectively, were used to test the biogas potential of different main products of plants. For the detailed investigations from sugar beet: the whole plant, pressed pulp, molasses and vinasse; from Jerusalem artichoke leaf and stem, tuber, pressed pulp (after inulin production) and a mix of leaf-stem (50%) and pressed pulp (50%), were used and replicated three times.

Examination of quality:

Before starting the biogas tests the dry matter content (50g sample in 50 °C, 24-48h) and organic dry matter content (incineration in 500 °C) from all materials were examined. The carbon content was counted from organic dry matter content.

Testing biogas production:

- Preparation of solid materials: to homogenize the samples of the solid materials were grinded to chop about 4mm size.
- Type of fermentor: 1,5 l size connected with gas meter.
- Starting the tests: the samples with 15g dry matter content were mixed into 1,5 l anaerob inoculation material (after biogas test without gas production).
- In each case a parallel investigation was launched with the inoculation materials only to test their biogas production.
- Fermentation conditions: the temperature of fermentor 39±0,5 °C, 7-8 pH, and manual stirring once a day.
- Measurements: the quantity and quality of biogas was measured every day. During the quality tests the concentration of methane, carbon-dioxide, oxygen and hydrogen sulfide were measured with GA 5000 bio-gasmeter. The pH and temperature were controlled at each turn.
- Investigation of end-product: after the finish of biogas production (2-3 weeks depend on samples) the remaining fermentum was filtrated through a sieve with 2mm hole diameter. The dry matter content of remaining material from the filter was examined in drying owen (50 °C, 24- 48h).

Calculation of gas and energy yields:

- Fermentation of dry matter (approximate value): dry matter content of raw sample – dry matter content of end-product (%)
- Biogas yields: the produced biogas per one unit of applied substance (dry matter, organic dry matter and raw material) (m^3 per t)
- Methane yields: biogas yields × methane contents (m^3 per t)
- Energy yields: methane yields × calorific value of methane (35,4 MJ per m^3) (GJ per t)

Calculation of energy potentials of regions:

The energy potentials based on biogas productions were calculated on the levels of European Union, the EU countries in Danube –region and in Hungary. Because the data of areas and yields (from Eurostat) are available only for silage maize and sugar beet only they both were analyzed.

First the maximum, average and flexible ((maximum-minimum) per 2) areas were determined from 25 years and 8 years (after sugar reform to 2015) Eurostat data. The flexible areas from the analyzis of last 8 years were assumed able to use for bioenergy production without disturbing the food production.

The energy yields per hectare were counted from energy yields based on comparison of the results from biogas production with bibliographic data and from the yield data of Euorostat. At last the total energy potential of silage maize and sugar beet from biogas production were determined for different regions.

Nutrition field trials:

Between 2007 and 2010 three-three field trials were conducted with corn and winter wheat by using the sludge from biogas plant of Sugar Factory Kaposvár.

The small plot trials (15 m^2 per plot) were located near Sopronhorpács on brown forest soils, with 4 repetition.

In each case the dry matter, organic matter, nitrogen, phosphorus, potassium, macro- and micro nutrient concentration were examined in an accredited laboratory after the Hungarian standards.

Before launching and after harvest the trials soil sampling and investigation were made from each plot. For determination of yields and moisture content of winter wheat plot harvester Shampo type were used. The plots of corn were harvested by hand.

Treatments:

1. Untreated control
2. 40 t sludge per ha
3. 80 t sludge per ha

Analytic testing of sludge:

Dry matter was investigated in drying owen after (MSZ 08-1783-1:1983 2.)

For determination of organic matter the air-dried material was incinerated in furnace (MSZ 318-3:1979).

The contents of nitrogen and phosphorus, were investigated after disruption with sulphuric acid (MSZ 20135:1999. and MSZ 08-1783-1:1983.). Toxic-mutrient concentration were examined with Spectro Genesis ICP OES after the Hungarian standard (MSZ 21470-50:1998.).

Soil tests:

The parameters, that are important for nutrient supply were examined in an accredited laboratory after the Hungarian standards. Among these are the macro- and micro-nutrient with toxic element as well.

Investigation of quality of yields:

Moisture content of corn was examined by using near infrared spectroscopy with Foss Infratech instrument.

The protein concentration and hectoliter weight of winter wheat were measured with Foss Infratech, too.

Statistical methods:

The results from biogas production experiments were evaluated with analysis of variance by using the DSAASTAT computer software.

The linear regressions and standard deviations were counted with MS Excel 2010.

For the analysis of variance for nutrition experiments the Statdirect software was used.

In each case the significant differences were detected with the Newman-Keuls test.

Theses

1. In the batch biogas fermentation experiments the methane yields of organic dry matter from silage maize, sorghum and sugar beet varieties were average 264.2; 287.9 and 361.3 m^3/t (**Table 1**). The average methane contents of biogas were 55.3% (Sd. 1.88) by silage maize, 53.0% (Sd. 1.64) by sorghum and 59.5% (Sd. 2.31) by sugar beet.

The variances in yields and quality of biogas draw attention to the potentials of plant breeding for energy production.

Table 1. *The average methane yields from organic dry matter and methane contents from batch biogas fermentation of silage maize, sorghum and sugar beet varieties, with their standard deviations.*

	Methane production from organic dry matter (m^3 per t)	Standard deviation (Sd.) of menthane production	Methane content of biogas (%)	Standard deviation (Sd.) of menthane content
Silage maize	264.2	18.7	55.3	1.88
Sorghum	287.9	18.5	53.0	1.64
Sugar beet	361.3	11.4	59.5	2.31

2. The different possibilities for biogas production from sugar beet, as in large areas cultivated crop for industrial processing were investigated in details. The sugar beet pressed pulp gave the highest methane yield from organic dry matter (409 m^3 per t) followed in descending order whole plant (381.1 m^3 pert), a molasse (378.5 m^3 per t) and vinasse (330.5 m^3 per t). The methane concentration of biogas from vinasse was 55% and from the other investigated materials about 60%.The biogas and methane productions from dry matter and organic dry matter are presented in **Table 2**.

Table 2. *The average biogas and methane production from sugar beet whole plant and processing by-products on the basis of dry matter and organic dry matter. (Different letters in the same columns indicate significant differences (P<5%))*

	Biogas production from dry matter (m^3 per t)	Biogas production from organic dry matter (m^3 per t)	Methane production from dry matter (m^3 per t)	Methane production from organic dry matter (m^3 per t)
Sugar beet pressed pulp	656.4 a	693.2 a	387.3 a	409.0 a
Sugar beet whole plants	605.3 b	635.1 b	363.2 b	381.1 b
Molasse	493.3 c	630.9 c	296.0 c	378.5 c
Vinasse	293.9 d	601.0 d	161.6 d	330.5 d

3. During the biogas production tests of Jerusalem artichoke, another crop grown for industrial processing too, but much less growing area than sugar beet, the average biogas yield of one unit organic dry matter and the methane concentration from the tuber of Jerusalem artichoke was the highest (438.6 m^3 per t and 62%). From the pressed pulp (408.7 m^3 per t and 60%), from the leaf-stem (272.3 m^3 per t and 58%) and from the mix of leaf-stem (50%) and pressed pulp (50%) methane were obtained referring to organic dry matter. The results of biogas and methane productions from different part and processing by-product of Jerusalem artichoke are presented in **Table 3**.

Table 3. *The average biogas and methane production from from different part and prosessing by-product of Jerusalem artichoke on the basis of dry matter and organic dry matter.*

	Biogas production from dry matter (m^3 per t)	Biogas production from organic dry matter (m^3 per t)	Methane production from dry matter (m^3 per t)	Methane production from organic dry matter (m^3 per t)
Jerusalem artichoke stem with leaves	437.5 d	469.4 d	253.8 d	272.3 d
Jerusalem artichoke tuber	662.8 a	707.3 a	410.9 a	438.6 a
Jerusalem artichoke pressed pulp	635.6 b	681.2 b	381.3 b	408.7 b
Mix of leaf-stem (50%) and pressed pulp (50%)	486.1 c	525.5 c	272.2 c	294.3 c

4. Based on the average winter wheat and corn yields 2010 - 2015 and biogas production data from measurements and calculations the energy yields per hectare from sugar beet could be 188.5 GJ on the level of European Union, 170.7 GJ and 182.1 GJ on the level of EU countries of Danube-region and Hungary. By calculating with silage maize this values would have been 116.3, 119.1 and 94.0 GJ per ha. The results are demonstrated on **Figure 1, 2 and 3**.

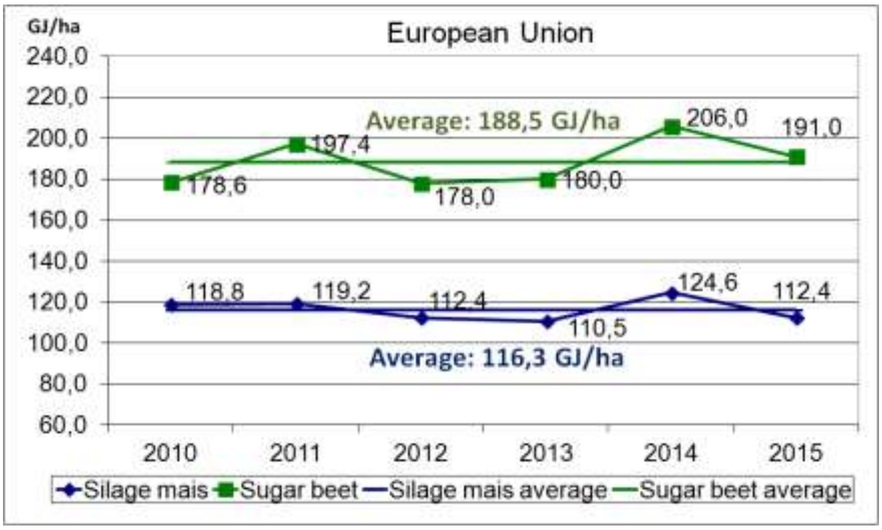

Figure 1. *The possible energy yields from biogas production based on the average yields of silage maize and sugar beet in European Union between 2010-2015.*

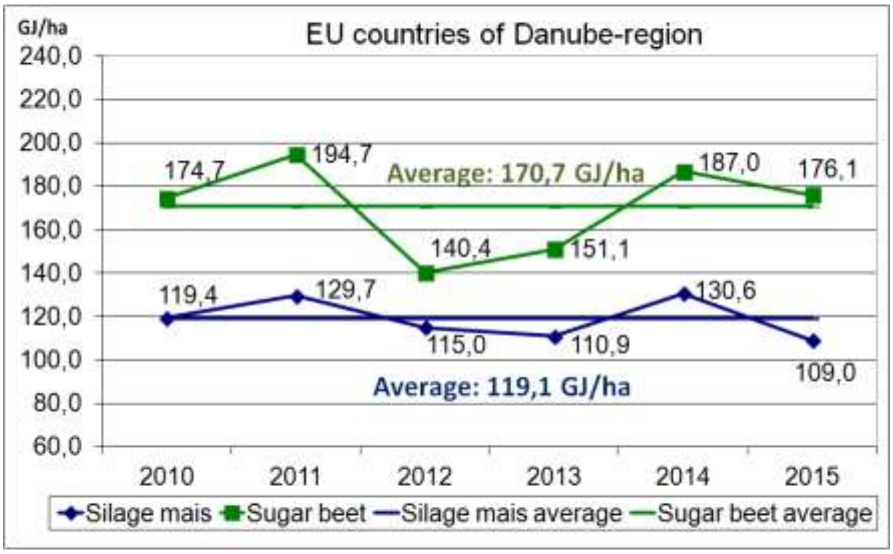

Figure 2. *The possible energy yields from biogas production based on the average yields of silage maize and sugar beet in EU countries of Danube- region between 2010-2015.*

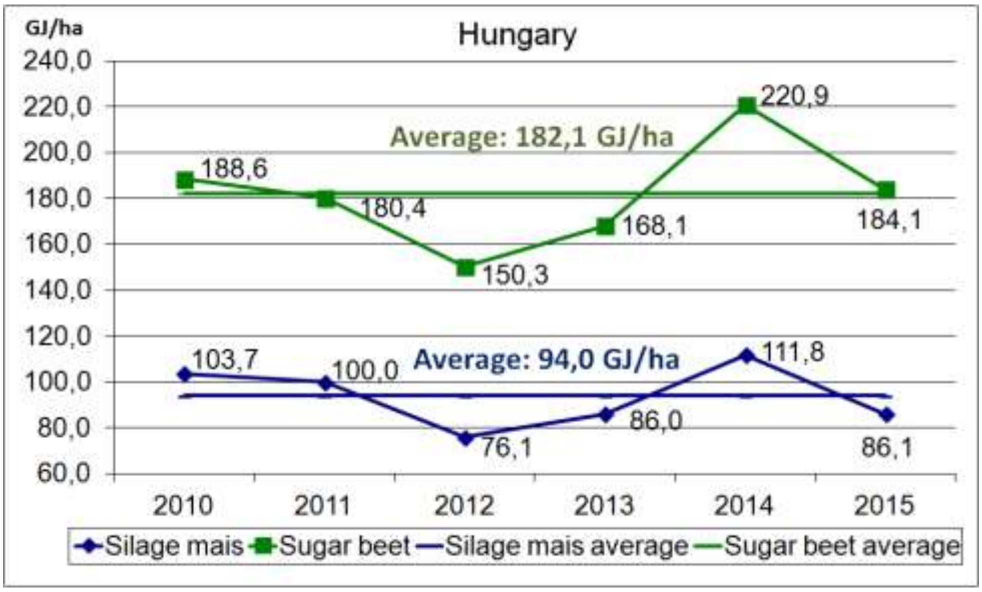

Figure 3. *The possible energy yields from biogas production based on the average yields of silage maize and sugar beet in Hungary between 2010-2015.*

5. After the calculation with the flexible areas of silage maize in European Union from the cultivation of silage maize it is possible to produce 85.408 PJ energy by biogas production. With the usage of the same type of areas from EU countries in Danube-regions and from Hungary 35.352 PJ and 1.113 PJ could be received. By calculation with sugar beet energy potential and its flexible areas 34.739 PJ, 15.660 PJ and 0.869 PJ would be produced from biogas (**Table 4**).

Table 4. *The maximum, average and flexible areas with possible total energy productions of different regions (The maximum and the average areas were calculated from the data of last 25 years and flexible areas were calculated from the data 2008-2015).*

Silage mais	Maximum		Average		Flexible	
	Area	Energy potential	Area	Energy potential	Area	Energy potential
	1000 ha	PJ	1000 ha	PJ	1000 ha	PJ
Hungary	321	37.337	148	17.218	9.57	1.113
Danube-region	4247	398.973	2333	219.211	376.28	35.352
EU 28	8134	968.589	5211	620.592	717.21	85.408
Sugar beet						
Hungary	161	30.347	65	12.345	4.61	0.869
Danube-region	1430	260.287	846	154.108	86.02	15.660
EU 28	3491	595.680	2339	399.199	203.57	34.739

6. The 40 and 80 t/ha doses of biogas sludge, which came from biogas production of sugar beet pulp increased the yields of winter wheat and corn in brown forest soils near Sopronhorpács, with good nutrient supply level as well. The relative yield rise was 4.4% and 8.1% by corn and 7.7% and 8.9% by winter wheat (**Figure 4 and 5**). The protein content of winter wheat increased significant (4.2%) with the 40 t per ha doses and 8.2% with 80 t per ha doses.

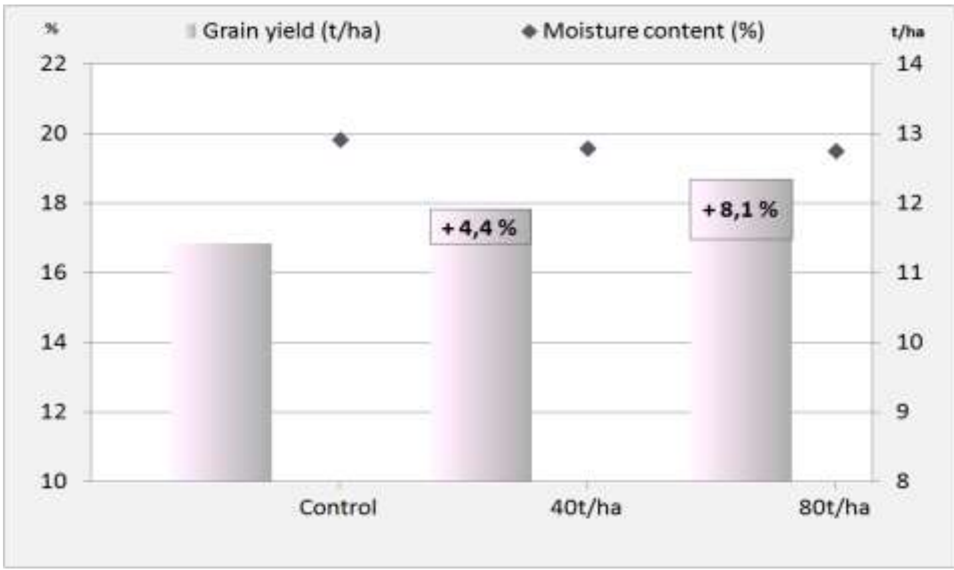

Figure 4. *The three years average of grain yield and moisture content of corn in nutrition trials with sludge from biogas production of sugar beet pressed.*

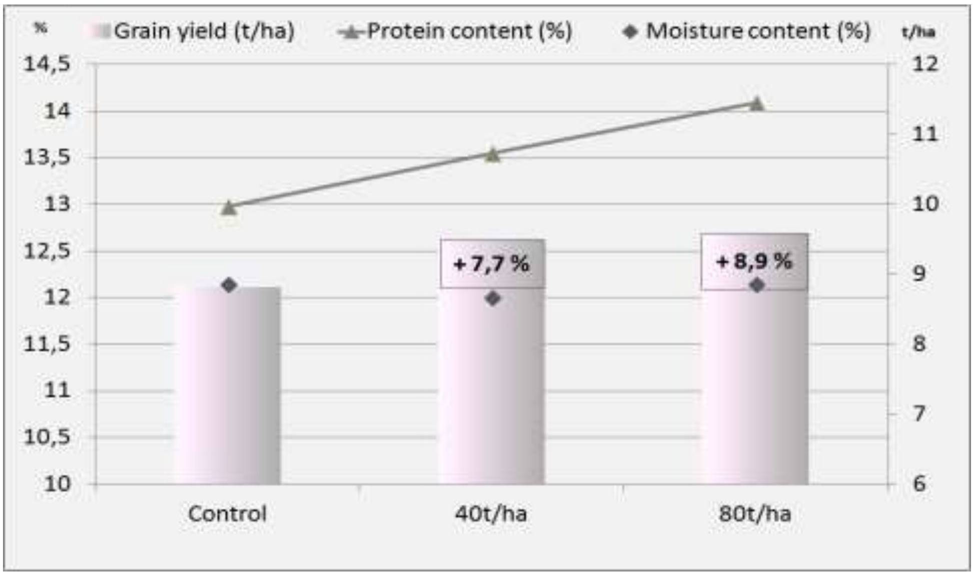

Figure 5. *The three years average of grain yield, moisture and protein content of winter wheat in nutrition trials with sludge from biogas production of sugar beet pressed.*

7. Expect sodium and nitrite nitrate nitrogen the different doses of biogas sludge have no significant effect on chemical element concentrations of soils (**Figure 6 and 7**). The average (both plants and three years) sodium concentration was increased with 19.3% and 21.6% due to 40 and 80 t per ha sludge treatments. The negative effect can be protected with professional planning of sludge application. The nitrite nitrate nitrogen content in corn trials has increased with 64.4% and 190.3% and in winter wheat trials with 72.7% and 157.5% compared to control. From this a stimulant effect on soil life (nitrification) is suggested.

The contents of heavy metals in sludge and of toxic elements in treated soils not exceed the limits from the relevant Hungarian laws.

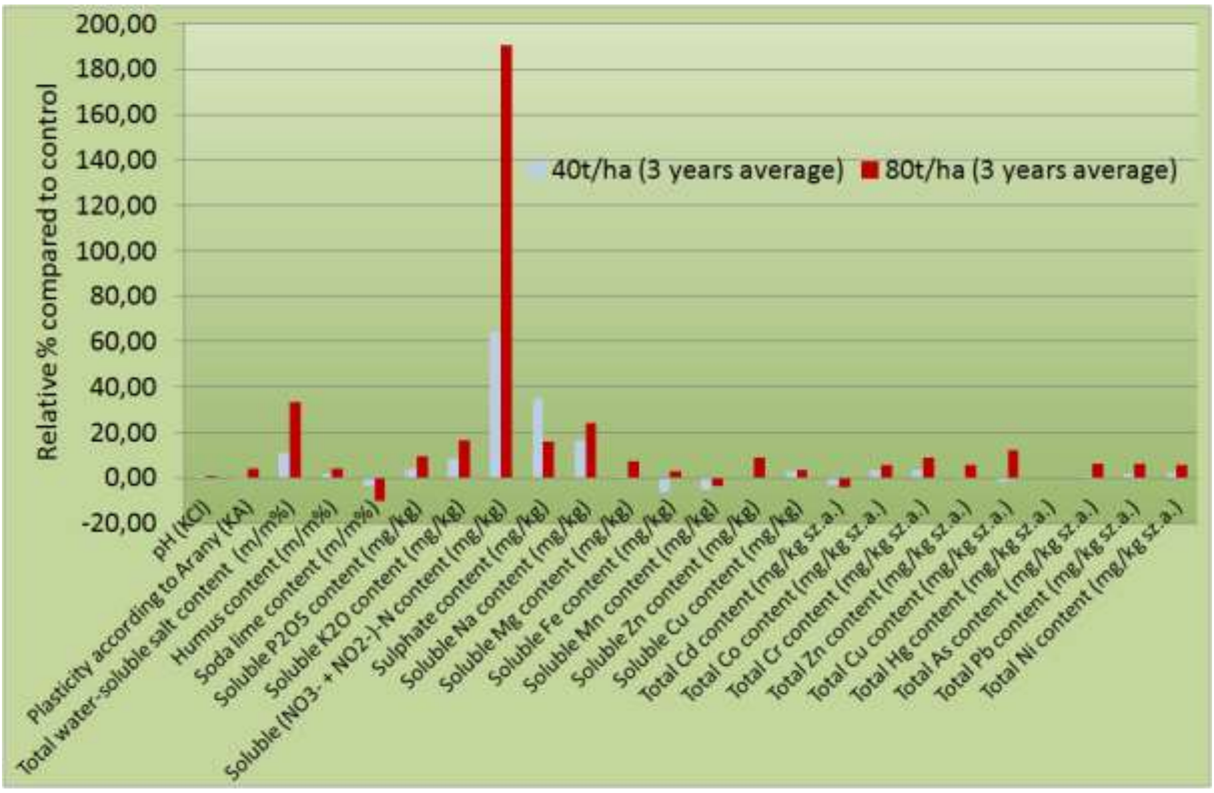

Figure 6. *The changes of soil parameters due to treatments of biogas sludge in corn trials (3 years average).*

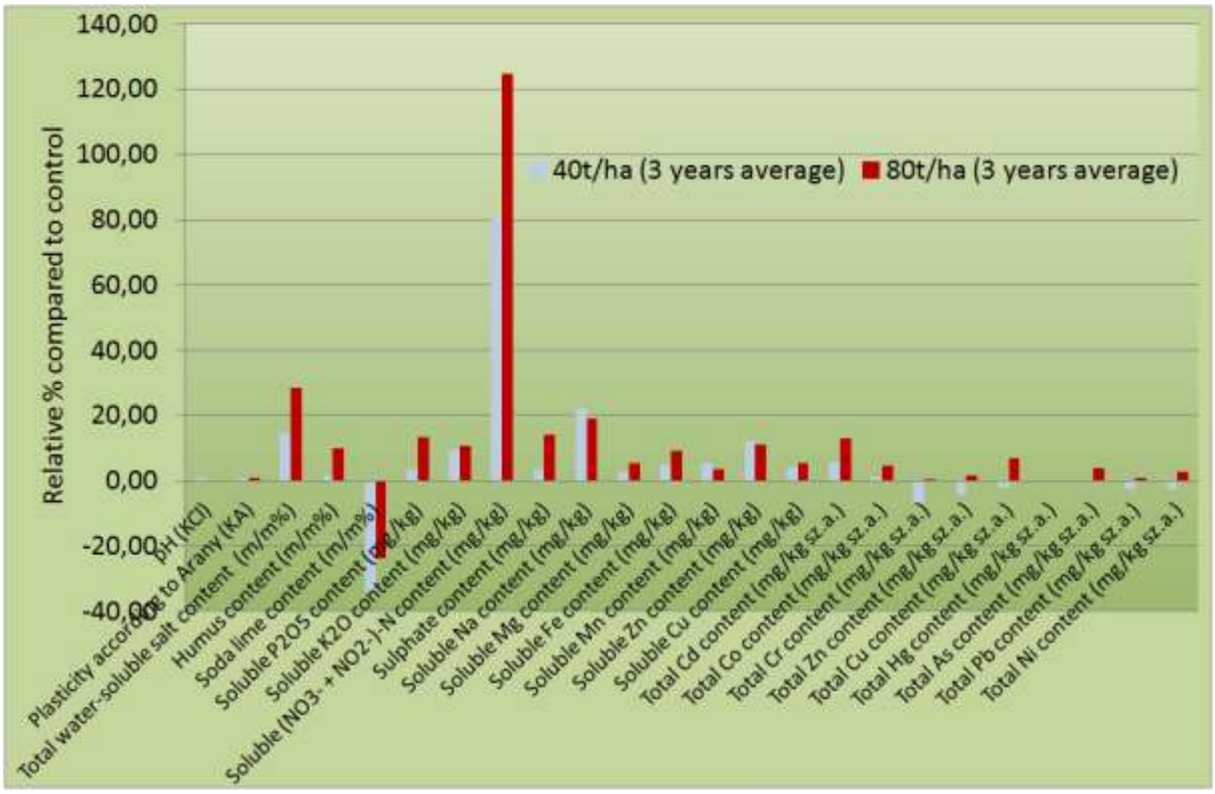

Figure 7. *The changes of soil parameters due to treatments of biogas sludge in winter wheat trials (3 years average).*

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