

# Studies on technological quality of sugar beets and soil parameters in relation to method of soil fertilization

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**Abstract**— *The aim of the studies was to determine suitability of effluent from methane digestion of organic wastes generated during processing of sugar beets for soil application at sugar beet plantations. In the paper parameters of technological value of sugar beet roots harvested from plots with standard values (i.e. optimal values for processing) which were defined by the Institute are discussed. It was shown that effluent from digestion of sugar beet pulp can be utilized as soil amendment on sugar beet plantations without any restrictions bearing in mind content of heavy metals and harmful microorganisms. Nutrients contained in studied effluent from gasifier are available for sugar beet plants at the same level as nutrients from mineral fertilizers. Determination of heavy metals in soil samples taken before and after effluent application did not reveal accumulation of harmful elements in the soil in the result of waste utilization.*

**Keywords**— *digestion effluent, fertilization, soil, sugar beet, sugar beet technological value.*

## I. INTRODUCTION

Root of sugar beet for processing purposes should show good health status, natural colour and shape, cannot be wilted, frozen or lignified. Technological value of sugar beet is described in the literature as a complex of biological, physical and chemical properties of root which determines positive effects of processing on effectiveness of white sugar gain. The essential roots' traits affecting quality of sugar beets are as follows: Biological- shape of root determining content of mineral impurities; resistance to diseases; resistance to bolters production; suitability for storage; chemical -content of sucrose; content of marc; content of  $\alpha$

– amino acid nitrogen and amide nitrogen; content of sodium and potassium; content of invert sugar; content of conductometric ash, content of dry matter, Physical - resistance to outer effects; resistance to outer effects; resilience module; coefficient of diffusion; mean root weight; in tissue compliance to slicing (Malec et al. 2007).

At the high extend quality of feedstock determines the proper course of processing as well as losses of sucrose and efficiency of white sugar gain. In modern sugar factories processing of sugar beet roots into white sugar does not create any technical problems if factory receives roots directly from plantations or after relatively short time storage.

Anyway during campaign of sugar beet processing weather creates lot of problems which result in serious technological problems and final effects are financial losses. The basic factor which often has deterioration effect on status of stored sugar beet roots is temperature. Too low temperatures cause freezing of roots whereas too high temperature results in starting of biochemical processes and development of moulds what degrades quality of roots (Gajewnik 2015).

It is widely known that sugar beets have high requirements concerning soil quality. The medium structured soils are optimal (optimal are medium loams and sandy clay) however high yields can be gained also on heavy clay.

The main parameters of soil for growing sugar beets are as follows: deep plough layer; high content of humic substances; soil reaction close to pH 7.0; good texture; balanced water properties; resistance to sliming and clodding.

The main factor determining sugar beet yield as well as its technological quality is fertilization. Deficits of nutrients in the soil result in yield reduction and their excess is also unfavourable because can considerably affect quality of roots. Sugar beet is one of crops most susceptible to nutrients imbalance in the soil because natural soil fertility cannot cover high crop demands and application of synthetic fertilizers and organic amendments is necessary (Malec et al. 2007).

During the processing of sugar beet roots into white sugar a high amount of beet pulp is generated which has been used as a feed for ruminants. High water content of the pulp which directly increases transportation and storage cost was a prerequisite to searching of new option of effective application of this by-product. The second prerequisite is connected with sharp decrease of cattle number and specialisation in agricultural sector, farm which grows sugar beets often does not run animal production and therefore does not need sugar pulp.

According to EU regulations in Poland share of energy from renewable sources should reach 14% in 2020 (Witek 2008). At the moment biomass is considered as a main source of renewable energy in Poland and is produced on arable lands from short-rotation coppice willow plantations where *Salix viminalis* and some other willow hybrids are grown (Berruto et al. 2013, Szczukowski et al. 2003).

Option of nutrients recycling by application of organic amendment i.e., effluent from methane digestion of beet pulp can be treated as environmentally friendly closing of nutrients turnover cycle what is desirable for sustainability of agricultural system (Bachmann et al. 2014, Chen 2012).

At the moment in Poland the problem of management of effluent from gasifiers processing different organic feedstocks is difficult because certificate for soil application is necessary if company does not receive this certificate the only alternative is incineration what because of high cost (700 PLN ~ 170 € Mg<sup>-1</sup>) makes investment in gasifier unprofitable.

It is known that soil application of effluent from methane digestion at plantation of *Salix viminalis* is currently under studies and first obtained results are promising (Urban 2011, Zając 2011).

So far no publication about application of sugar beet effluent at plantations of sugar beets was found. Therefore our studies were undertaken to determine suitability of application of effluent from methane digestion of beet pulp and other organic wastes as an organic amendment on sugar beet plantation.

## II. MATERIALS AND METHODS

Studied materials were: soil samples, effluent after methane digestion of beet pulp and sugar beet roots harvested from experimental plots (sugar beet cv. *Fighter*). Studies were conducted in growing season of 2013 at sugar beet plantation owned by Institute of Agricultural and Food Biotechnology in Leszno, Poland. Just before beets planting soil samples from topsoil layer were taken to determine soil basic chemical and microbiological properties. Then fertilization treatments were established in triplicate and the rate of nitrogen 120 kg N ha<sup>-1</sup> was applied as synthetic fertilizer or appropriate rate of effluent from methane digestion of beet pulp. After sugar beets harvesting estimation of technological properties for processing was performed using 5 randomly selected roots and soil samples were then taken. The following analytical methods of soil samples were applied: pH – potentiometric; total nitrogen – by Kjeldahl distillation; nitrate nitrogen – spectrophotometric; nitrites – diazo process; ammonia and amide nitrogen – titration with water steam; presence of parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp. according to Polish National standards; magnesium and calcium – titration; potassium, cadmium, nickel, chromium, copper, sodium and zinc – AAS; mercury – AAS in amalgamate. The following method of sugar beet analyses were applied: total nitrogen – by Kjeldahl distillation;  $\alpha$  – amino acid nitrogen – spectrophotometric; total phosphorus – valandium molybdenic method; sucrose – polarimetric; reductive compounds – titration; conductometric ash – potentiometric method.

## III. RESULTS AND DISCUSSION

Agricultural utilization of organic wastes (including effluent from methane digestion) is possible only if requirements set by Regulation given by the Minister of Environment on 13<sup>th</sup> July 2010 are fulfilled. Mentioned requirements concern soil properties as well as wastes.

Requirements concern soil where wastes are intended to be applied and the quality of wastes.

In mentioned Regulation permissible levels of heavy metals in topsoil are specified if wastes are applied to the soil.

In Table 1 these requirements are presented together with analytical results of soil samples from experimental field.

As it can be noticed from data presented in Table 1 concentration of all studied heavy metals in soil from experimental field was lower than permissible threshold irrespectively of agronomical category of the soil: light, medium of heavy textured.

**TABLE 1**

**COMPARISON OF PERMISSIBLE LEVELS OF HEAVY METALS IN TOPSOIL (0-25 CM DEPTH) FOR AGRICULTURAL UTILIZATION OF WASTES WITH RESULTS OF DETERMINATION OF SOIL SAMPLED AT EXPERIMENTAL FIELD ( $\text{mg kg}^{-1}$ )**

Metal	Results of determination of soil from experimental field	Permissible level of given metal in three types soil for utilization of organic wastes		
		light	medium textured	heavy
Cadmium (Cd)	< 0.50	$\leq 1$	$\leq 2$	$\leq 3$
Lead (Pb)	24	$\leq 40$	$\leq 60$	$\leq 80$
Nickel (Ni)	8.0	$\leq 20$	$\leq 35$	$\leq 50$
Chromium (Cr)	12.0	$\leq 50$	$\leq 75$	$\leq 100$
Mercury (Hg)	< 0.050	$\leq 0.8$	$\leq 1.2$	$\leq 1.5$
Copper (Cu)	16.0	$\leq 25$	$\leq 50$	$\leq 75$
Zinc (Zn)	46.0	$\leq 80$	$\leq 120$	$\leq 180$

In Table 2 chemical characteristics of digestion effluent is given. The waste was then applied to the soil at experimental field. It was found that waste can be applied to the soil without any restrictions as far as food or feed crops are concerned.

**TABLE 2**

**THE QUALITY OF DIGESTION EFFLUENT APPLIED AT EXPERIMENTAL FIELD ON THE BACKGROUND OF PERMISSIBLE LEVELS**

Parameter	Unit	Results	Permissible level
Soil reaction	pH-H <sub>2</sub> O	7.8	—*
Dry matter (DM)	% fresh matter	2.5	—
Organic substances	% DM	55.8	—
Cadmium (Cd)	$\text{mg kg}^{-1}$ DM	2.73	$\leq 20$
Lead (Pb)	$\text{mg kg}^{-1}$ DM	17.1	$\leq 750$
Nickel (Ni)	$\text{mg kg}^{-1}$ DM	5.51	$\leq 300$
Chromium (Cr)	$\text{mg kg}^{-1}$ DM	29.6	$\leq 500$
Mercury (Hg)	$\text{mg kg}^{-1}$ DM	0.543	$\leq 16$
Copper (Cu)	$\text{mg kg}^{-1}$ DM	108	$\leq 1000$
Zinc (Zn)	$\text{mg kg}^{-1}$ DM	846	$\leq 2500$
Calcium (Ca)	$\text{mg kg}^{-1}$ DM	129	—
Magnesium (Mg)	$\text{mg kg}^{-1}$ DM	4.02	—
Total nitrogen Kjeldahls' N	$\text{g kg}^{-1}$ DM	38.4	—
Total phosphorus (P)	$\text{g kg}^{-1}$ DM	12.6	—
Potassium (K)	$\text{g kg}^{-1}$ DM	2.25	—
Salmonella	in 100 g	not found	0
Number of living eggs of: <i>Atrichuris</i> sp., <i>Trichuris</i> sp., <i>Tococara</i> sp.	$\text{kg}^{-1}$ DM	not found	0

\* not specified in the Regulations of Minister of Environment

In Table 3 mean values of selected quality indices of sugar beet roots are presented on the background of optimal values for sugar beet roots processing which were elaborated by the Institute.

**TABLE 3**  
**COMPARISON OF QUALITY INDICES OF SUGAR BEETS HARVESTED FROM EXPERIMENTAL FIELD WITH THE OPTIMAL VALUES OF GIVEN INDEX FOR PROCESSING IN SUGAR FACTORY**

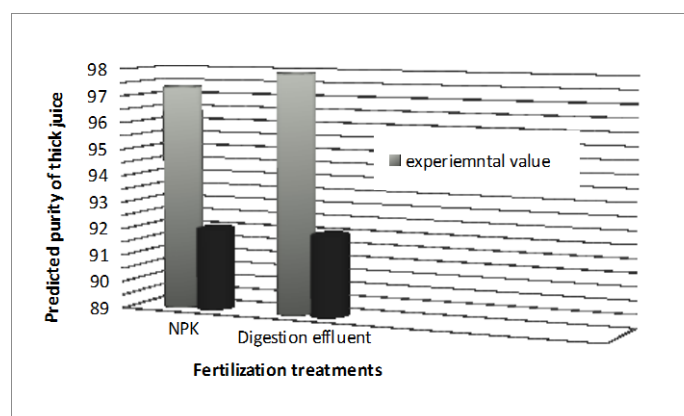
No	Item	Optimal value for processing	Results of determination:		LSD (t-Student P = 0.05)
			mineral fertilizers 120 kg N ha <sup>-1</sup>	digestion effluent 120 kg N ha <sup>-1</sup>	
1.	Cz <sub>sg</sub> – predicted purity of thick juice 99.36 - 0.1427 ( Na+ K +α – N)	> 92	97.3	97.9	0.5
2.	„Purity” index Ck % × 100/dry matter %	> 70	81	77	NS
3.	Ck <sub>m</sub> - predicted sugar content in molasses according to Wieninger’s 0.349 (Na + K)	< 2	1.3	1.0	NS
4.	WAI – alkalinity index with invert sugar Na+K/α – N +I	>1,8	3.1	2.2	NS
5.	Ash index Ck %/ash %	> 40	60	64	NS
6.	Index of α – amino acid nitrogen Ck %/ α – N %	> 800	2341	3050	NS
7.	Amide nitrogen index Ck %/ amide N %	> 750	1545	1426	290.2
8.	Index of reductive substances Ck % / reductive substances %	> 100	261	177	65.5
9.	Nonsugar index Ck %/ soluble nonsugar%	> 10	4	4	NS
10.	Index of potassium alkalinity K %/ α – N %	> 8	15	17	NS
11.	Index of ash alkalinity ash %/ α – N %	> 15	38	48	NS

\*Ck %- content of sucrose; NS–not significant;

In Table 3 comparison of technological value indices of sugar beets harvested from plot of two experimental treatments is given.

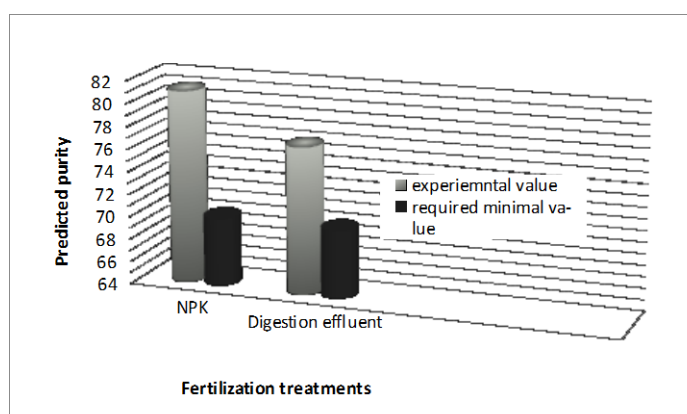
For sugar factories processing of sugar beets all listed quality indices are very important because they determine technological value of sugar beet roots. It is connected that processing of sugar beets consists of several technological phases and each requires specific conditions determined by: time, temperature and pH of solutions and juices.

Eleven indices i.e., their optimal values and obtained for harvested sugar beet roots are listed in Table 3.



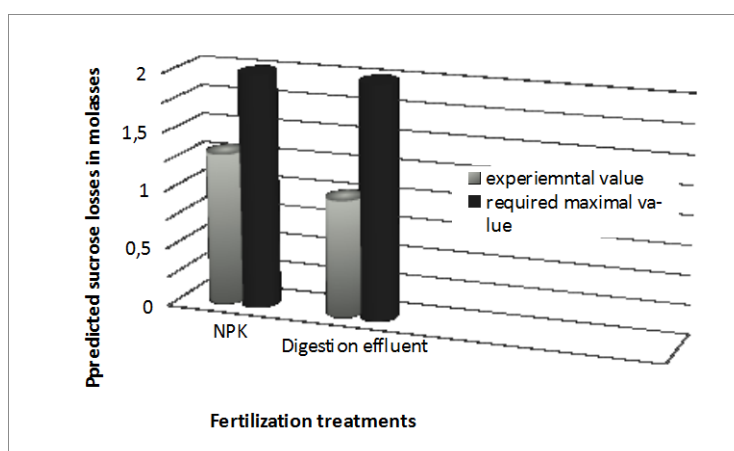
**FIG. 1 MODIFICATIONS OF PREDICTED PURITY OF THICK JUICE IN RELATIONS TO FERTILIZATION TREATMENTS**

Predicted purity of thick juice obtained for sugar beet roots in the experiment was higher than optimal i.e., > 92% and for treatment with mineral fertilizer and digestion effluent amounted to 97.3 and 97.9%, respectively. It was found that this difference was statistically proven at  $P = 0.05$ .



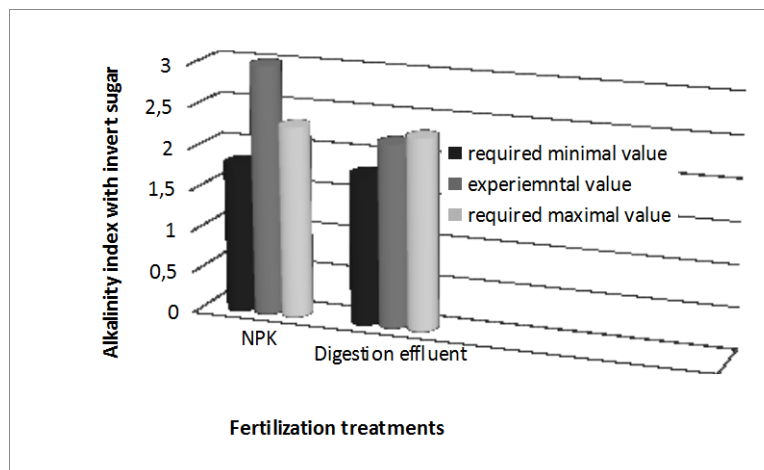
**FIG. 2 MODIFICATIONS OF PREDICTED PURITY IN RELATIONS TO FERTILIZATION TREATMENTS**

“Purity” index of sugar beet roots (i.e., percentage of sucrose in dry matter) was higher than optimal (70%) and it amounted to 81 and 77% for treatment with mineral fertilizer and digestion effluent, respectively but this significance of differences was not found.



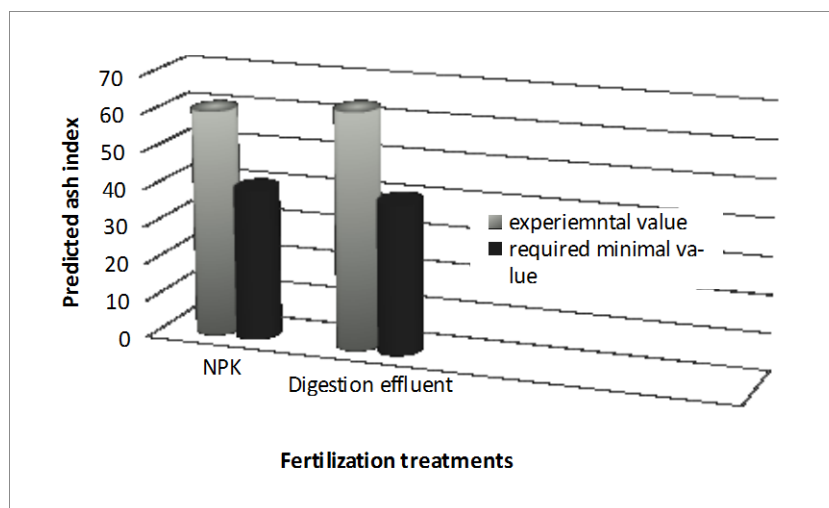
**FIG. 3 MODIFICATIONS OF PREDICTED SUCROSE LOSSES IN MOLASSES IN RELATIONS TO FERTILIZATION TREATMENTS**

Predicted amount of sucrose in molasses according to Wieninger's formula when taking into account only sodium and potassium is regarded as optimal when is lower than 2%. For roots harvested from treatment with mineral fertilizer and digestion effluent amounted to 1.3 and 1.0%, respectively. Losses of sucrose in molasses are considered as the main source of sugar losses during processing so its high importance of this parameter for sugar factory. From obtained results it is evident that both treatments did not negatively affected quality of sugar beet roots but difference was not significant at  $P = 0.05$ .



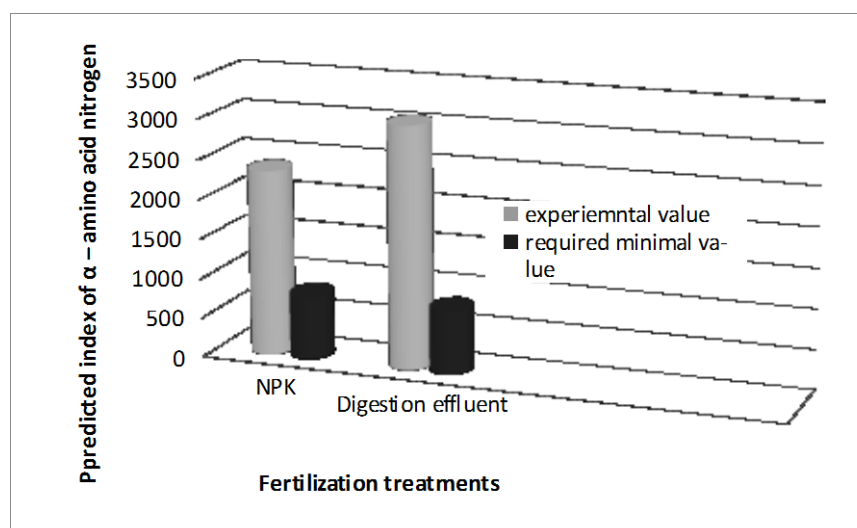
**FIG. 4 MODIFICATIONS OF ALKALINITY INDEX WITH INVERT SUGAR IN RELATIONS TO FERTILIZATION TREATMENTS**

Values of alkalinity index with invert sugar (WAI) amounted to 3.1 and 2.2 for roots harvested from plots with mineral fertilization and application of digestion effluent, respectively. Mentioned values were higher than recommended for processing (1.8). A higher value means that reaction of juices (from diffusion juice to thin clarified juice) is alkaline what ensures lower losses in whole technological process. From obtained results it can be concluded that no additional costs are needed for processing sugar beet roots harvested from fields amended with digestion effluent. According to ANOVA results differences between two studied treatments were not significant.



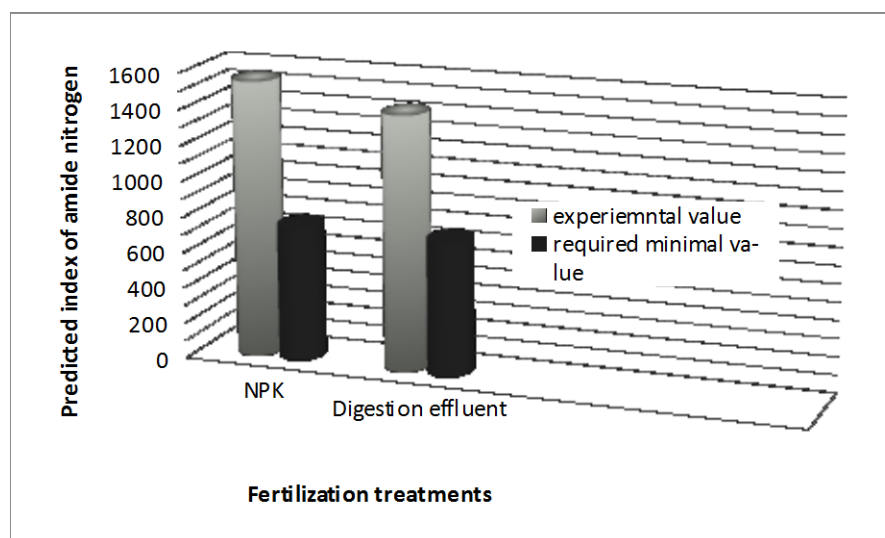
**FIG. 5 MODIFICATIONS OF PREDICTED ASH INDEX IN RELATIONS TO FERTILIZATION TREATMENTS**

Values of ash indices have to be considered as optimal for sugar beet roots processing when they are higher than 40. For both studied treatments value of this index amounted to ca. 60 because of low ash concentration in sugar beet roots. Differences of ash index values between studied treatments were not significant at  $P = 0.05$ .



**FIG. 6 MODIFICATIONS OF PREDICTED INDEX OF A – AMINO ACID NITROGEN IN RELATIONS TO FERTILIZATION TREATMENTS**

Value of  $\alpha$  – amino acid nitrogen was substantially higher than it was assumed. It can negatively affect processing of sugar beet roots because of juice colour modifications and reduction of alkalinity. To overcome it higher dose of lime has to be applied what increase processing cost. It was found for roots of both treatments and method of fertilization has not significant effect on this parameter.

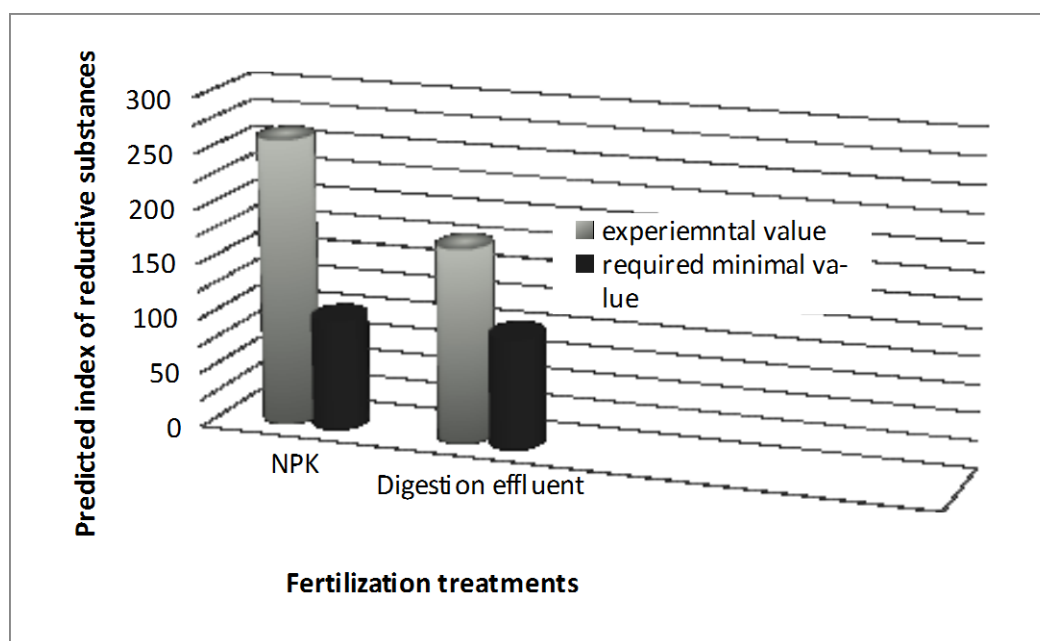


**FIG. 7 MODIFICATIONS OF PREDICTED INDEX OF AMIDE NITROGEN IN RELATIONS TO FERTILIZATION TREATMENTS**

Amide compounds are undesirable in sugar production because their chemical and thermal degradation takes a long time and the final product is gaseous nitrogen. Reduction of amide compounds in feedstock is profitable for sugar factories.

Partly degraded amide compounds are responsible for: reduction of juices pH; pollution of condensates in evaporators which are directed to steam boilers which give technological steam to turbines.

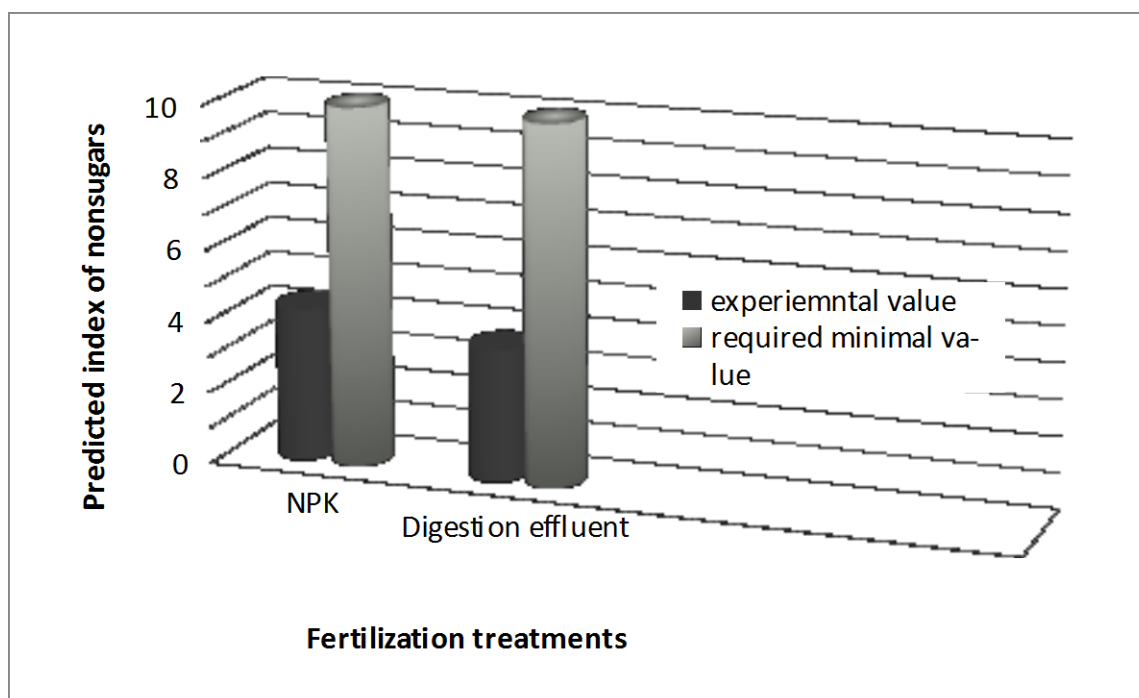
Index of amide nitrogen should be higher than 250. Samples of sugar beet roots harvested from experimental plots irrespectively of the method of fertilization showed optimal value of this index. Roots harvested from plot treated with mineral fertilizer showed significantly higher value of amide nitrogen index comparing to roots fertilized with digestion effluent.



**FIG. 8 MODIFICATIONS OF PREDICTED INDEX OF REDUCTIVE SUBSTANCES –INVERT SUGAR IN RELATIONS TO FERTILIZATION TREATMENTS**

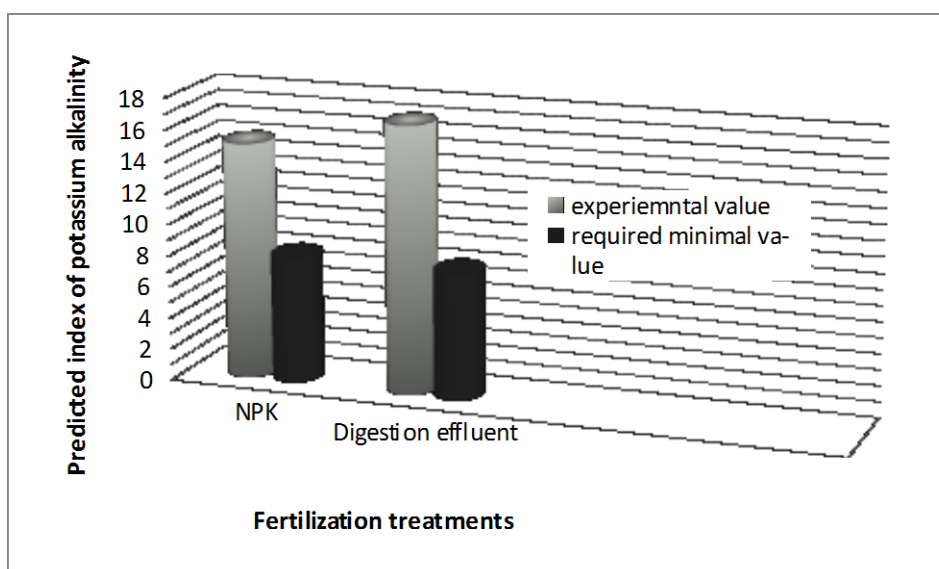
Reductive substances unfavourably affect processing of sugar beet roots because of: generation of coloured products in reaction with amino acids; necessity of application of high rates of lime during clarification of juices; degradation of invert sugars to different by-products and among them lactate acid and reduction of juice pH because organic acids are generated.

Limited amount of invert sugars in roots indicates stabilization of this simple sugar in cell vacuole. From obtained results can be concluded that this index was optimal for sugar beet roots processing and in case of roots harvested from plots fertilized with mineral nitrogen this index value was significantly higher than for roots from plots amended with digestion effluent.



**FIG. 9 MODIFICATIONS OF PREDICTED INDEX OF NONSUGARS IN RELATIONS TO FERTILIZATION TREATMENTS**

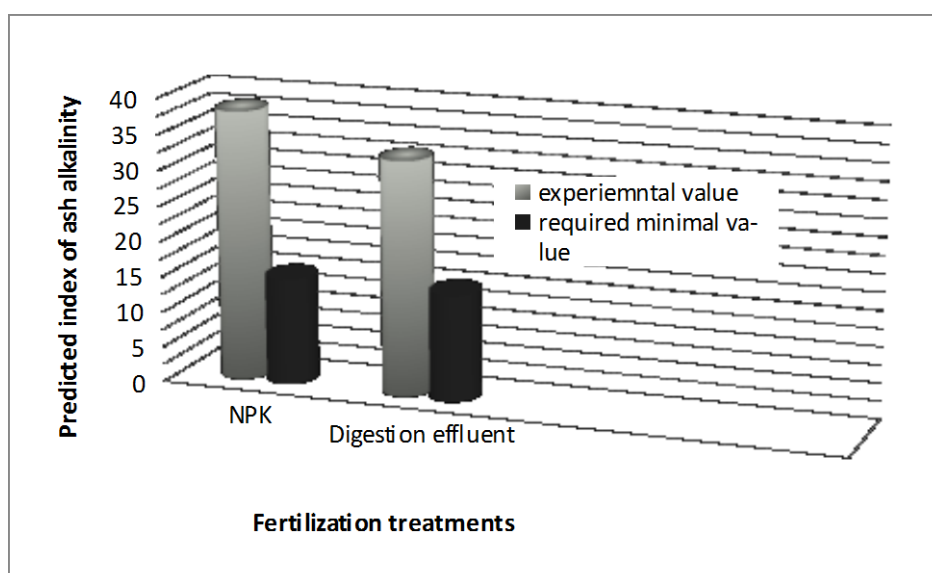




**FIG. 10 MODIFICATIONS OF PREDICTED INDEX OF POTASSIUM ALKALINITY IN RELATIONS TO FERTILIZATION TREATMENTS**

Values of nonsugar index were lower than low threshold considered as optimal what indicated that quality of roots was lower than optimal irrespectively of the fertilization treatment.

Index of potassium alkalinity should be higher than 8 and index of ash alkalinity higher than 15. Free cations and easily soluble potassium and sodium salts present in juice represent so called 'natural juice alkalinity'. Cations and salts have positive role because they maintain alkaline i.e., desirable pH of juice but they are effective only at appropriate concentration. If this concentration is too low than sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) has to be applied. Optimal values have to be treated as thresholds and if actual values are lower at the stage of saturation water solution of soda has to be added to achieve molasses pH at 7.2 – 8.2. Under conditions of full scale production it result in higher losses of sugar in molasses because soda generates more molasses than magnesium or calcium compounds.



**FIG. 11 MODIFICATIONS OF PREDICTED INDEX OF ASH ALKALINITY IN RELATIONS TO FERTILIZATION TREATMENTS**

From obtained results it can be concluded that both indices of alkalinity showed values optimal for processing of sugar beet roots irrespectively of fertilization treatment under studies.

Generally it was found that sugar beet roots harvested from experimental plots showed satisfactory level of studied quality indices for processing for both studied fertilization treatments.

After sugar beet harvesting soil analyses were repeated.

Data from Table 4 show modifications of soil chemical parameters in the growing period of sugar beet on experimental field with two fertilization treatments.

**TABLE 4**  
**COMPARISON OF CHEMICAL PARAMETERS OF THE SOIL BEFORE AND AFTER GROWTH OF SUGAR BEET**  
**UNDER CONDITIONS OF TWO FERTILIZATION TREATMENTS**

Parameter	Unit	Before sugar beet planting	After sugar beet harvesting	
			mineral fertilizers 120 kg N ha <sup>-1</sup>	digestion effluent 120 kg N ha <sup>-1</sup>
Soil reaction	pH-H <sub>2</sub> O	7.6	8.3	8.3
Dry matter (DM)	% fresh matter	84.2	81.5	83.3
Organic substances	% DM	2.7	2.8	2.6
Cadmium (Cd)	mg kg <sup>-1</sup> DM	< 0.50	< 0.50	< 0.50
Lead (Pb)	mg kg <sup>-1</sup> DM	24.0	37.0	33.0
Nickel (Ni)	mg kg <sup>-1</sup> DM	8.0	7.5	8.4
Chromium (Cr)	mg kg <sup>-1</sup> DM	12.0	20.0	16.0
Mercury (Hg)	mg kg <sup>-1</sup> DM	< 0.050	< 0.050	< 0.050
Copper (Cu)	mg kg <sup>-1</sup> DM	16.0	22.0	21.0
Zinc (Zn)	mg kg <sup>-1</sup> DM	46.0	55.0	46.0
Calcium (Ca)	mg Ca kg <sup>-1</sup> DM	7270	8800	8030
Available magnesium	mg Mg kg <sup>-1</sup> DM	54	55	54
Total nitrogen Kjeldahls'	mg N kg <sup>-1</sup> DM	1340	1020	920
Available phosphorus	mg P kg <sup>-1</sup> DM	460	600	540
Available potassium	mg K kg <sup>-1</sup> DM	44	35	32

As it can be concluded from results presented in Table 4 that soil analysed after sugar beets harvesting contained high concentration of nutrients –amendment with digestion effluent ensured high fertility of experimental soil: nitrogen – 920 (before) and 1340 mg N kg<sup>-1</sup> DM (after harvesting); phosphorus – 540 (before) and 460 mg P kg<sup>-1</sup> DM (after harvesting); potassium – 32 (before) and 44 mg K kg<sup>-1</sup> DM (after harvesting).

Summing up obtained results it can be stated that macronutrients present in digestion effluent were available for plants. No significant differences between availability of macronutrients from mineral fertilizers and digestion effluent were found. Soil after sugar beet growing period showed higher concentration of calcium and phosphorus irrespectively of fertilization treatments applied. Initial content of calcium in the soil was 7270 mg Ca kg<sup>-1</sup> DM and after sugar beets harvesting 8030 and 8800 for treatment with digestion effluent and mineral fertilizer, respectively; initial content of phosphorus in the soil was 460 mg P kg<sup>-1</sup> DM and after sugar beets harvesting 540 and 600 for treatment with digestion effluent and mineral fertilizer, respectively.

Heavy metals analysis in the soil showed that accumulation in the soil of cadmium, nickel and mercury was not noted. However, in case of lead, chromium, copper and zinc increase of their content in the soil was found but agricultural suitability of soil was not changed.

#### IV. CONCLUSION

Effluent after digestion of sugar beet pulp can be applied to the soil bearing in mind content of heavy metals and microbes.

It cannot be stated which method of fertilization (mineral fertilizer or digestion effluent) with rate of 120 kg N ha<sup>-1</sup> was better in terms of technological quality of feedstock for sugar factory.

Evaluation of technological quality of sugar beet roots harvested from experimental field performed on the base of quality criteria has shown that sugar beet roots from both treatments fulfilled those criteria.

In the soil analysed after sugar beet harvesting high concentration of essential nutrients was found what indicated that soil was not depleted and maintained high fertility.

Nutrients from digestion effluent were available for sugar beet plants in the same level as from mineral fertilizers. Soil after growing sugar beets was enriched of calcium and phosphorus irrespectively of fertilization treatment.

Determination of heavy metals in experimental soil before sugar beet planting and after harvesting did not show any accumulation of cadmium, nickel and mercury and in case of lead, chromium, copper and zinc their elevated level cannot cause any threats for crops and the environment..

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