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EFFECT OF CROP ROTATION AND FERTILIZATION OF SUGAR BEET ON THE FORMATION OF MAXIMUM BIOETHANOL YIELD

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Abstract

The purpose of research is to evaluate the efficiency of growing sugar beet for bioethanol as affected by a fertilization system, tillage, and soil moisture zone. The study was conducted in the Forest-Steppe of Ukraine under the conditions of insufficient and unstable soil moisture. It was found that growing sugar beet for bioethanol should be aimed at increasing their productivity through the practicing of organic-mineral fertilization and using cattle manure or straw. For the cultivation of sugar beet, the most effective are those crop rotation units that contain legumes or, if insufficient soil moisture, the units which include bare fallow. It was found that in the area of insufficient soil moisture, fertilization factor determined bioethanol yield by 44 %, while in the zone of unstable moisture by 55%. At the same time, in the area of insufficient soil moisture, the effect of crop rotation unit increases as a factor ensuring a sufficient level of soil moisture available to the plants (26%), and in the area of unstable soil moisture, these factors affect bioethanol yield by only 19 %. By analogy, the weather factor in the insufficient soil moisture zone has a greater effect on bioethanol yield (20%) than in the unstable soil moisture zone (14%). In addition, the total impact of a crop rotation unit and weather conditions in the area of insufficient soil moisture is higher than fertilization treatment. Sugar beets, under the conditions of insufficient soil moisture, provide a yield level high enough to produce 3.18 t/ha of bioethanol at the production cost of $ 0.40 per litre, while for growing maize bioethanol yield will be 1.41 t/ha at the production cost of $ 0.59 per litre. Under the conditions of unstable soil moisture, bioethanol yield per unit area of maize grows to 2.45 t/ha; however, this crop cannot be compared to sugar beet in terms of efficiency, although production costs are approximately equal. By applying a sufficient package of agronomic practices, it is possible to obtain a sufficiently high yield of bioethanol from sugar beet roots, even under the conditions of insufficient soil moisture. To optimize sugar beet nutrition under the conditions of insufficient soil moisture it is recommended to incorporate post-harvest straw residues over the background of $N_{140}P_{90}K_{90}$, and under the conditions of unstable soil moisture to apply 50 t/ha of manure + $N_{100}P_{100}K_{100}$.

Keywords : Sugar beet; fertilization system; tillage; renewable energy; bioethanol.

Introduction

Ukraine experiences a significant deficit of its fossil fuels and can ensure the need in them only by 50 %, the need in oil by 10–12 %, and the need in natural gas up to 30%. This situation poses a threat to the energy security of the country and requires immediate resolution by involving biological fuel resources that are renewable sources of stored solar energy (Babenko, 2017). The use of biomass as a source of fuel and the elimination of non-renewable energy sources will minimize environmental pollution by toxic substances and greenhouse gases. After all, the issue of reducing CO_2 emissions into the atmosphere is extremely important today. Therefore, in Ukraine, it is advisable to investigate the use of renewable energy sources, especially based on traditional agricultural feedstock (Roik *et al.*, 2017; Kaletnik & Pryshliak, 2010). Compared to gasoline, bioethanol produced from sugar beets has less impact on the environment (Bessou *et al.*, 2013), with overall greenhouse gas emission decreasing from 28 to 42 %. The main gas released from the combustion of bioethanol is CO_2, which corresponds to the natural carbon cycle (Halleux *et al.*, 2008).

In Europe, a well-developed biofuel development strategy is being implemented and Germany is currently the leader in biofuel production. To illustrate, Germany produces 1/3 of renewable energy generated in the European Union. By 2030, the EU plans to produce about 50% of alternative energy sources. By introducing bioethanol production technologies, the European Union aims to eliminate dependency on energy imports and prevent global warming. There are already nine bioethanol plants operating in Europe, with five of them using solely sugar beet as a feedstock (one in France, the United Kingdom and the Czech Republic, two in Germany) (Schwarz, 2011; Ruppert, 2011). Bioethanol production is considered the most rational use of sugar beet, whereas biogas is more cost-effective (Hartmann, 2018). Worldwide bioethanol is produced in different countries from the crops most common in a particular region. For example, in Brazil, it is sugar cane, and in the US, it is maize. However, the production of bioethanol from sugar beet is considered one of the simplest processes compared to the production of ethanol from grain crops (Gumienna *et al.*, 2016).

Sugar-bearing crops serve a feedstock primarily for bioethanol (Anasontzis *et al.*, 2016; Dunn and Rao, 2015; He *et al.*, 2014). Apart from bioethanol, they are used to produce biobutanol (Jiang *et al.*, 2015; Ndaba *et al.*, 2015; Zheng *et al.*, 2015), and there are also papers describing the process of biomethane (De Vriezea *et al.*, 2014) and biohydrogen production (Abbasi and Abbasi, 2011; Das and Veziroglu, 2008).

For the production of liquid biofuels, sugar beet can be considered one of the most promising crops, which is also suitable for growing in the Forest-Steppe of Ukraine under the conditions of both insufficient and excessive soil moisture. Thus, in 2019, sugar beets were grown on an area of 221.9 thousand hectares, while in the period from 1990 to 1999, the area was 1.0–1.6 million hectares (State Statistics Service of Ukraine, 2019). That is why there are significant reserves to increase the production of sugar beet for processing them into biofuels. Moreover, economic forecasts state that in Ukraine, the area of sugar beet for bioethanol may reach 72.6 thousand hectares by the end of 2020 (Bondar, 2013).

The productivity of sugar beet as an effective feedstock for the production of bioethanol depends on their genetic potential. Therefore, high-yielding hybrids resistant to abiotic factors and diseases are suitable for these purposes (Roik *et al.*, 2014; Roik and Kornieieva, 2015).

Fertilization system for sugar beet grown for bioethanol should be based on a positive balance of organic matter with the use of mineral and organic fertilizers in livestock farms, incorporation of crop residues into the soil for sugar beet and in crop rotation on the whole (Tsvei, 2014; Zarishniak *et al.*, 2015).

The use of intermediate crops as green manure, for example, growing white mustard, contributes to soil organic matter balance, the recirculation of CO_2 in an agroecosystem, and an increase in the sugar beet yield (Koch, Haukeer-Jakol, 2007). Optimization of the sugar beet fertilization practice enables obtaining high root yield and sugar yield. Under the conditions of biologization and greening of crop fertilization, along with the use of mineral fertilizers, significant amounts of cattle manure and harvest residues are practiced (Cordes, 2014; Minth. 2014; Schlink, 2016).

The goal of the study was to investigate the effect of crop rotations and fertilization practice on sugar beet yield and quality as a feedstock for bioethanol production.

Methods and Materials

The studies aimed at studying the effect of sugar beet fertilization system, tillage practice, and crop rotation units on yield and quality of sugar beet for the production of bioethanol were conducted in different soil and climatic zones of Ukraine.

In the zone of insufficient soil moisture (annual air temperature averages 7.8 °C, and rainfall 520–530 mm) under the conditions of Veselyi Podil Research Breeding Station, the experiment was carried out in the short crop rotations units, on the typical slightly saline chernozem with the following agrochemical characteristics: pH_{Salt} of 7.0–7.2, humus content of 4.5 %, mobile phosphorus content of 50 mg/kg, and exchange potassium content of 110 mg/kg. The layout of the experiment and the fertilization system for sugar beet in crop rotation units is given in Table 1.

In the zone of unstable soil moisture (average annual air temperature 7.5 °C, rainfall 550–580 mm), the experiment was carried out in the Bila Tserkva Research Breeding Station in crop rotation unit with vetch and oats and winter wheat on typical leached chernozem with the following agrochemical soil characteristics: pH_{Salt} of 5.5–5.8, humus content of 3.5–3.6 %, mobile phosphorus content of 180–200 mg/kg of soil, exchangeable potassium content of 80 mg/kg. The layout of the experiment and the fertilization system are given in Table 2.

Sugar beet fertilization treatments have been designed to enrich the soil with nutrients in a particular zone of soil moisture. Growing technology for the experiment was generally accepted in the region except for the studied items.

The experiment was conducted in a randomized plot design with four replications in plots of an area of 100 m^2.

The test plots were seeded with a domestic triploid sugar beet hybrid ‘Zluka’ that is well adapted to cultivation under conditions of unstable and insufficient soil moisture.

The yield was determined plot by plot, followed by calculation per hectare. The sugar content of the sugar beet roots was determined using technological line Venema by the method of cold digestion.

Dispersion and cluster analyses were used to statistically evaluate the results of the field studies. The cluster analysis was performed by the method of joining tree clustering using the single linkage and Euclidean distances rule. As a result of clustering, a horizontal hierarchical tree (dendrogram) was built.

The calculation of bioethanol and renewable energy yield was carried out according to the methodical recommendations (Methodical recommendations for the technology of growing sugar beet for bioethanol).

Results and Discussion

The results of the study confirmed the data obtained by other researchers, i.e. the productivity of sugar beets and the yield of bioethanol are affected not only by a fertilization system but also by crop rotation and soil moisture provision in a particular agricultural region.

In the zone of insufficient soil moisture (Veselyi Podil Research Breeding Station), on the typical slightly saline chernozem, in short, crop rotation unit with esparcet and fescue grass, over the background of harvest residues (straw) incorporation + $N_{140}P_{90}K_{90}$, 39.8 t/ha of roots was obtained with sugar yield of 6.91 t/ha and bioethanol yield of 3.18 and renewable energy of 79.5 GJ/ha, respectively. In the crop rotation, where sugar beets were sown in the unit with silage maize, their yield was inferior to that of the unit with esparcet and fescue grass by 4.1 t/ha and the sugar yield by 0.77 t/ha. The difference was due to the efficiency of biological nitrogen, the after effect of which can be also observed in root yield, which was 35.7 and 6.14 t/ha, respectively, while the yield of bioethanol and energy reached 2.82 and 70.5 GJ/ha, respectively.

Table 1 : Sugar beet productivity indicators and bioethanol yield in the area of insufficient soil moistening as affected by a fertilization practice (VPRBS, 2016-2018)

Treatment No.	Treatment	Root yield (t/ha)	Sugar content (%)	Sugar yield (t/ha)	Bioethanol yield (t/ha)	Energy yield (GJ/ha)
Esparcet – fescue grass – winter wheat (crop rotation system)						
1	No fertilizers (no straw)	22.9	16.5	3.80	1.73	43.3
2	$N_{140}P_{90}K_{90}$ + straw	39.8	17.4	6.91	3.18	79.5
Silage maize – winter wheat (hoed crop rotation)						
3	No fertilizers (no straw)	21.6	16.7	3.67	1,65	41.3
4	$N_{140}P_{90}K_{90}$ + straw	35.7	17.2	6.14	2,82	70.5
Bare fallow – winter wheat (grain – fallow crop rotation)						
5	No fertilizers (no straw)	25.6	16.5	4.26	2.02	50.5
6	$N_{140}P_{90}K_{90}$ + straw	38.5	16.8	5.22	3.09	77.3
Winter wheat – winter wheat (grain – hoed crop rotation)						
7	No fertilizers (no straw)	22.4	16.8	3.79	1.73	4.3
8	$N_{140}P_{90}K_{90}$ + straw	37.5	16.6	6.23	2.86	71.5
$LSD_{0,05}$		1.8	0.5	0.31	0.13	3.3

In the grain – fallow crop rotation, where sugar beets were grown in the unit with bare fallow, their root yield was not inferior to that obtained in the unit with esparcet and fescue grass. However, the sugar content of the roots was 0.6 % lower due to the increased nitrogen mineralization and its assimilation by plants, which reduced the sugar content of the roots by 0.6 %, and the sugar yield by 1.69 t/ha. In this crop rotation unit, bioethanol yield reached 3.09 t/ha, and energy yield reached 77.25 GJ.

In grain – hoed crop rotation dedicated to growing winter wheat and sugar beet, in the unit with winter wheat – winter wheat, on the background of fertilizers, root yield and sugar yield were 37.5 and 6.23 t/ha, respectively, and the yield of bioethanol and energy yield was 2.86 t/ha and 71.5 GJ/ha, respectively (Table 1).

Therefore, incorporation of winter wheat straw over the background of $N_{140}P_{90}K_{90}$ ensures bioethanol yield from 3.18 to 2.86 t/ha and energy yield from 79.5 to 70.5 GJ/ha.

The results of the clustering of the studied treatments by a set of sugar beet productivity indicators in the zone of insufficient soil moisture are shown in Fig. 1.

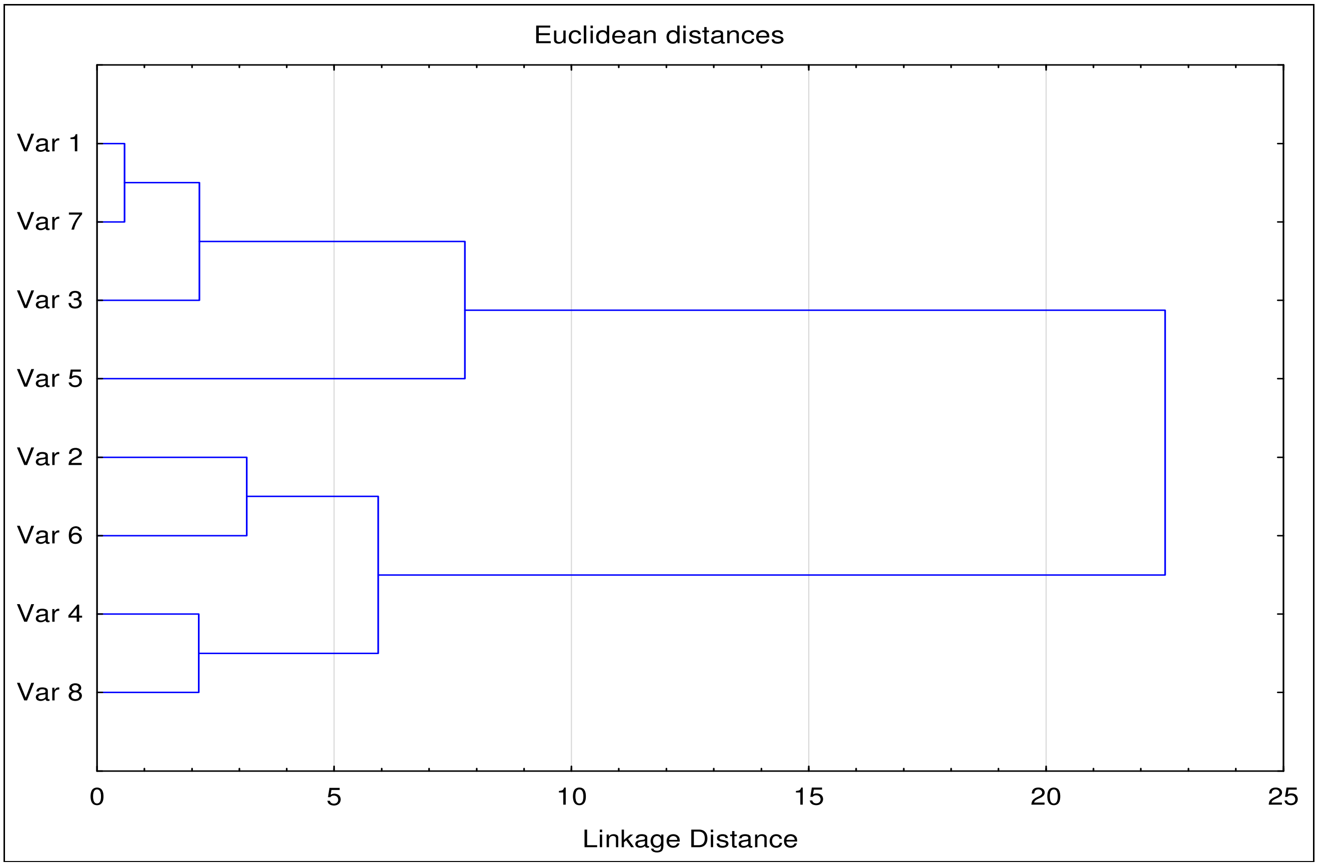

Fig. 1 : Clustering of fertilization treatments and crop rotation units by a set of sugar beet productivity indicators in the zone of insufficient soil moisture

Under the conditions of insufficient soil moisture, the studied treatments without fertilizers are grouped into one cluster (treatments 1, 7, 3, and 5), which not only proves the correctness of our experiment results but also shows a much greater influence of fertilization practice on the formation of sugar beet productivity compared to the influence of crop rotation option.

The following cluster is formed by sugar beet growing for the use of $N_{140}P_{90}K_{90}$ mineral fertilizers over the background of incorporated straw. However, within the cluster, it is possible to select a pool of variants grouped according to the features of a short crop rotation unit. Thus, the most similar are the following units: silage maize – winter wheat (treatment 4) and winter wheat – winter wheat (treatment 8). Here are the variants of rotation units with esparcet – fescue grass – winter wheat (treatment 2) and bare fallow– winter wheat (treatment 6), though more distant but grouped into one pool. The distance in the patterns of formation of the elements of sugar beet productivity and, respectively, the yield of bioethanol can be explained by the differences between these units in the accumulation of soil moisture and the availability of organic and mineral nutrients to plants.

In the zone of unstable soil moisture (Bila Tserkva RBS) on leached chernozem, where sugar beets were sown in the unit with vetch and oat over the background of 50 t/ha manure + $N_{100}P_{100}K_{100}$, root yield was 58.0 t/ha, sugar yield 9.21 t/ha, bioethanol yield 4.26 t/ha, and energy yield 106.5 GJ/ha, which exceeded the treatment without fertilization by 2.43 t/ha and 60.8 GJ/ha, respectively. The treatment with straw + $N_{100}P_{100}K_{100}$ ensured root yield and sugar yield not inferior to the above-mentioned fertilization system, whereby bioethanol and energy yield was 4.22 t/ha and energy yield 105.5 GJ/ha.

Table 2 : Sugar beet productivity indicators and bioethanol yield in the area of unstable soil moistening as affected by a fertilization practice (BTsRBS, 2014-2016)

Treatment No.	Treatment	Root yield (t/ha)	Sugar content (%)	Sugar yield (t/ha)	Bioethanol yield (t/ha)	Energy yield (GJ/ha)
Esparcet – fescue grass – winter wheat – sugar beet (crop rotation system)						
1	No fertilizers	23.8	16.8	3.97	1.83	45.8
2	$N_{100}P_{100}K_{100}$ + 50 t/ha of cattle manure	58.0	16.0	9.21	4.26	106.5
3	$N_{100}P_{100}K_{100}$ + straw	56.7	16.2	9.15	4.22	105.5
Silage maize – winter wheat – sugar beet (hoed crop rotation)						
4	No fertilizers	19.7	17.6	3.47	1.59	39.8
5	$N_{100}P_{100}K_{100}$ + 50 t/ha of cattle manure	53.4	16.9	8.90	4.14	103.5
Winter wheat – winter wheat – sugar beet (grain – hoed crop rotation)						
6	No fertilizers	22.8	17.4	3.95	1.82	45.5
7	$N_{100}P_{100}K_{100}$ + 50 t/ha of cattle manure	55.5	16.4	9.04	4.18	104.5
8	$N_{100}P_{100}K_{100}$	47.6	16.7	7.87	3.65	91.3
$LSD_{0,05}$		2.3	0.4	0.32	0.16	0.4

In the mineral fertilization treatment ($N_{100}P_{100}K_{100}$), root yield and sugar yield were lower compared to the treatment with 50 t/ha of cattle manure + $N_{100}P_{100}K_{100}$ by 7.9 and 1.17 t/ha, respectively and reached 47.6 and 7.87 t/ha, respectively. The yields of bioethanol and energy decreased to 3.65 t/ha and 91.3 GJ/ha, respectively (Table 2). Therefore, when practicing the organic-mineral fertilization system, it is possible to obtain sugar beet yield from 55.5 to 58.0 t/ha and bioethanol yield from 4.14 to 4.26 t/ha.

According to the results of the analysis, a tree of clustering of fertilization treatments and crop rotations was built based on a set of sugar beet productivity indicators in the zone of unstable soil moisture (Fig. 2).

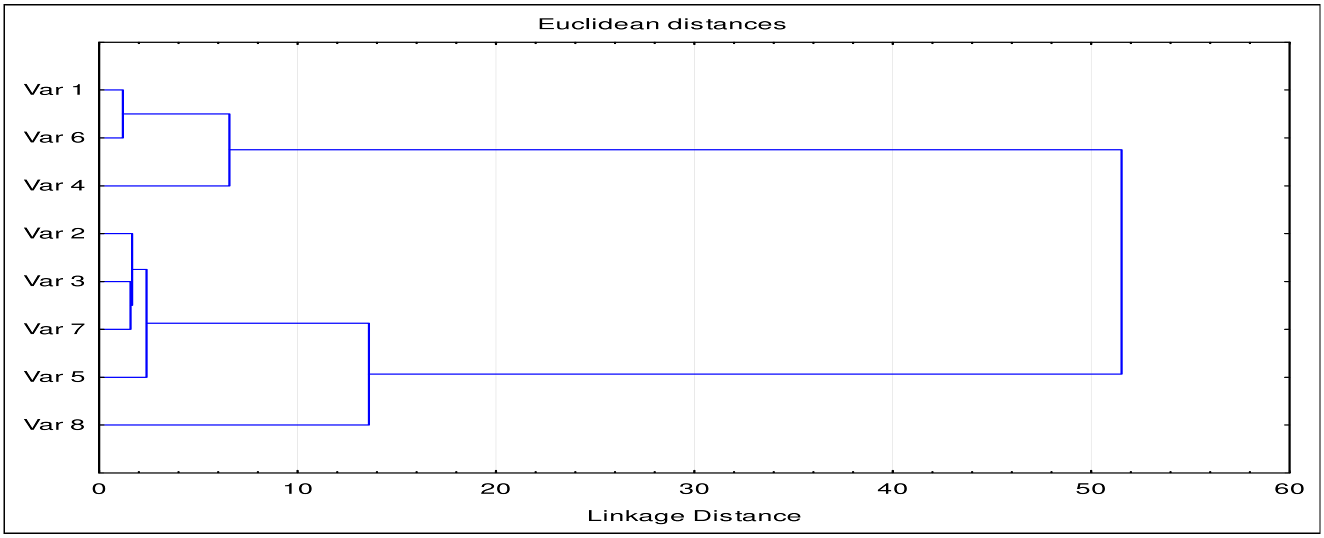

Fig. 2 : Clustering of fertilization treatments and crop rotation units by a set of sugar beet productivity indicators in the zone of unstable soil moisture

Cluster analysis of the experimental treatments under the conditions of unstable soil moisture also allows to distinguish patterns similar to the conditions of insufficient soil moisture. Thus, all treatments with no fertilization for sugar beet (treatments 1, 4, and 6) are grouped into one cluster.

In the second cluster, different fertilization treatments are concentrated. However, the closest in terms of the influence on productivity indicators are the treatments with 50 t/ha of cattle manure + $N_{100}P_{100}K_{100}$ regardless of crop rotation (treatments 2, 3 and 7), but treatments 7 and 8 are adjacent to the previous group.

The results of the analysis of the factors affecting the yield of bioethanol for the cultivation of sugar beet under the conditions of insufficient and unstable soil moisture are shown in Fig. 3-4.

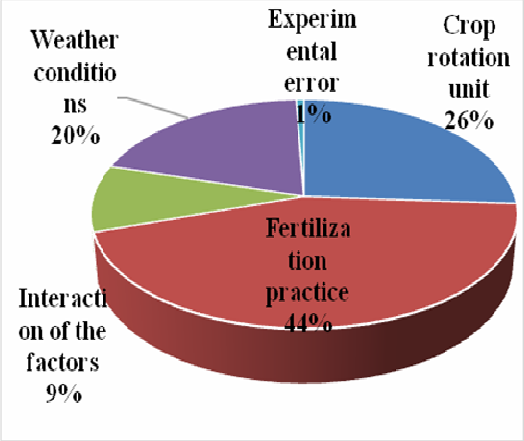

Fig. 3 : Influence of the studied factors on the bioethanol yield in the zone of insufficient soil moisture

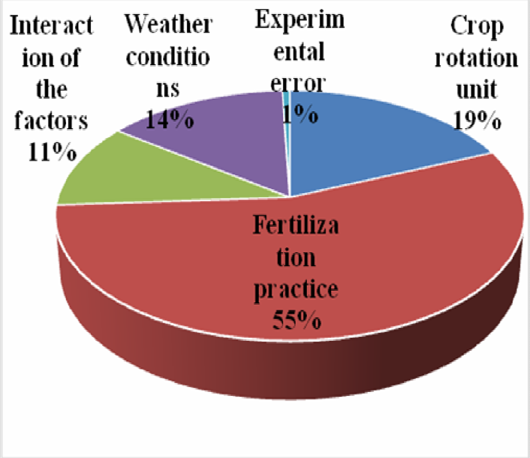

Fig. 4 : Influence of the studied factors on the bioethanol yield in the zone of unstable soil moisture

The study has demonstrated a significant effect of fertilization practice on the yield of bioethanol from sugar beet roots. Thus, in the zone of insufficient soil moisture, this factor influence made up 44 % and in the zone of unstable soil moisture 55 %. At the same time, in the zone of insufficient soil moisture, the influence of the crop rotation unit increases as a factor providing a sufficient level of moisture available to the plants in the soil (26 %), and in the zone of unstable soil moisture, these factors affect the level of bioethanol yield by only 19 %.

By analogy to the effects of crop rotation, weather conditions in the zone of insufficient soil moisture have a greater effect on the yield of bioethanol (20 %) than in the zone of unstable soil moisture (14 %). Moreover, the total impact of the crop rotation unit and weather conditions in the zone of insufficient soil moisture is higher than fertilization treatment. This again emphasizes the importance of the proper selection of crop rotation for the efficient accumulation of productive moisture and, as a consequence, the formation of high productivity and yield of bioethanol from sugar beets.

In general, bioethanol is an alternative fuel because it costs much less than the fuel produced from oil (Deverell *et al.*, 2009). However, in the total cost of growing feedstock and converting it into bioethanol, the actual cost of the feedstock may make up from 60 to 85% of the total cost of bioethanol production, which affects its competitiveness (Kwiatkowski *et al.*, 2006).

Data on the efficiency of growing sugar beet for bioethanol production compared with maize under the conditions of insufficient and unstable soil moisture are given in Table 3.

Table 3 : The efficiency of growing sugar beet for bioethanol compared to maize

Crop	**Yield (t/ha)**	**Bioethanol yield (t/ha)**	**Cost of 1 ton of feedstock ($)**	**Transportation and production costs per 1 ton of bioethanol ($)**	**Cost of 1 ton of bioethanol ($)***
Zone of insufficient soil moisture					
Sugar beet ($N_{140}P_{90}K_{90}$ + straw, crop rotation system)	39.8	3.18	27.8	163.7	0.40
Silage maize	3.4	1.41	250.0	144.2	0.59
Zone of unstable soil moisture					
Sugar beet ($N_{100}P_{100}K_{100}$ + 50 t/ha of cattle manure)	58.0	4.26	23.6	163.7	0.38
Grain maize	5.9	2.45	147.5	144.2	0.39

Note: * (for bioethanol density of 790 kg/m^3)

It was found that under the conditions of insufficient soil moisture, sugar beets provide a yield high enough to produce 3.18 t/ha of bioethanol, while maize only 1.41 t/ha. Under the conditions of unstable soil moisture, the yield of bioethanol per unit area of maize grows to 2.45 t/ha. However, this crop cannot be compared with sugar beets in terms of efficiency.

Overall, sugar beet is a good feedstock for the production of bioethanol by most technological parameters (Muñoz *et al.*, 2014). The processing of sugar beet roots consumes somewhat less energy than maize. Maize requires much more energy for starch hydrolysis than sugar beets require for syrup pasteurization. However, sugar beets require more transportation costs, and they are less suitable for long-term storage. Therefore, the integration of sugar and bioethanol production at existing sugar mills is promising (Weinberg and Kaltschmitt, 2013).

There are currently more than 60 sugar mills in Ukraine operating with their capacities loaded only by 40–50 %. In addition, domestic sugar beet hybrids are resistant to root rot and can be stored without significant loss of sugar from 2 to 3 months at a sugar mill.

A comparison of the economic elements of the efficiency of growing sugar beet for bioethanol demonstrates their advantage over other traditionally grown crops for these purposes. Thus, the cost of bioethanol production, taking into account the costs of growing and processing sugar beets in the zone of insufficient soil moistening, is $ 0.40 per litre, while for maize $ 0.59 per litre. The zone of unstable soil moistening does not allow to open up the potential of sugar beets and to reach a high level of productivity, while at the same time maize is comparable in terms of the production cost of bioethanol, although maize is significantly inferior to sugar beet in terms of the bioethanol yield per unit area.

Conclusions

The study has shown that given a comprehensive agronomic package (crop rotation and fertilization practice), a sufficiently high level of sugar beet productivity and bioethanol yield can be obtained, even in the zone of insufficient soil moisture.

It was found that in the zone of unstable soil moisture, crop rotation system is the most effective, whereas in the zone of insufficient soil moisture, the most effective will be crop rotation system (esparcet – fescue grass – winter wheat) and grain –fallow rotation (bar fallow – winter wheat).

To optimize the nutrition of sugar beet for the production of bioethanol under the conditions of insufficient soil moisture, it is advisable to use harvest residues (straw) over the background of $N_{140}P_{90}K_{90}$. This increases the yield of bioethanol from 2.86 to 3.18 t/ha and, accordingly, energy yield from 70.5 to 79.5 GJ at the production cost of $ 0.40 per litre.

Growing sugar beets under the conditions of unstable soil moisture in the crop rotation over the background of 50 t/ha of manure + $N_{100}P_{100}K_{100}$ contributes to obtaining bioethanol yield of 4.26 t/ha, which corresponds to 119.75 GJ/ha of renewable energy. Under such conditions, sugar beets are competitive in terms of cost-effectiveness of bioethanol production and its cost.

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