www.ees.uni.opole.pl
ISSN paper version 1642-2597
ISSN electronic version 2081-8319
Economic and Environmental Studies
Vol. 18, No.4 (48/2018),1219-1233, December 2018

Sustainable development for soya production based on the field research carried out at the Variety Assessment Experimental Station of Głubczyce in the years 2015-2017

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Abstract: The aim of this research was to determine the impact of various nitrogen fertilization systems in soya cultivation on quality and quantity of crop, as well as to examine the economic aspects of sustainable farming. The study was based on research carried out in the Variety Assessment Research Station of Głubczyce (years: 2015-2017). The soybean, protein and fat of four soya varieties (*Glycine max* (L.)Merrill) non-GMO (Augusta, Mavka, Aligator, Lissabon) were compared, using varying doses of N/ha (0, 30 and 60 kg). The cost effectiveness of the various fertilization doses was also determined. The soybean yields of the different soya varieties differed significantly, which indicates the existence of interdependence between weather conditions during growth and both quantity and quality. Fertilizing with 30 kg N/ha was the optimal rate both in terms of quality and quantity of the yield, as well as economically. The varieties of ‘Aligator’ and ‘Lissabon’ proved the best suited to the climate and environment of Głubczyce region, regarding significant LSD coefficients.

Keywords: sustainable development, soya, non-GMO, nitrogen fertilizer

JEL codes: Q01, Q19

DOI: https://doi.org/10.25167/ees.2018.48.3

1. Introduction

The sustainability of the environment in agricultural production is determined by maintaining the proper relationships between economic, human and natural capital (Smędzik-Ambroży, 2014).

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The principle of sustainable development can be defined as follows “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (Our Common Future… 1987). The principle of sustainable development in farming is determined by each system of cultivation and the plants’ impact on the natural environment which is either positive or negative.

Soya (*Glycine max* L.) is a plant that fulfills both ecological and economic aims. In terms of cultivated area, it is the fourth in the world and is grown on approximately 118 million ha (Maria John et al., 2015). The largest producers are the USA, Brazil, Argentina, India and China (FAOSTAT, 2018). In Poland, an insignificant amount of soya is grown due to the unsuitable climate, and the ease of importing genetically modified fodder. Recently there has been more interest in growing this crop in order to limit the import of GMO. Presently, in the UE catalogue of varieties, there are more than 400 genetically modified soya varieties and in the National Registration there are 12 (COBORU, 2017). In Poland, in 2017, soya was grown on 25.000 ha, and in 2016 this amount fell by approximately 50% due to a drop in the subsidies by about 70% (GUS, 2017). Furthermore, the easy access to imported genetically modified (GMO) fodder is another reason for the limited interest in soya cultivating.

Annually, Poland imports approximately 2.2 million tons of soybean meal worth 4 billion PLN. The use of plant protein in Poland is estimated to be 1.46 tons, of which 77% is imported (of this 90% is soybean meal). To develop the production of fodder protein it is expected that this will increase by 0.65 million tons, of which 0.3 million tons will come from fabaceae, 0.2 million tons from rapeseed meal and 0.15 million tons from other sources. The goal in the future is to increase protein production in Poland to meet 50% of the country’s needs. At the same time this would reduce its imports by 1 billion PLN (Kościelniak, Pyziak, 2017).

Furthermore, soya is an excellent forecrop of plants and it is one of the most important oil plants. In addition to the beans being rich in high quality protein (32-42%) and fat (18-22%) and commonly used in food production and in animal feed, it is also a very good element of balanced crop rotation and an excellent forecrop for successive plants. Also, its cultivation is positive both economically and environmentally (Kościelniak, Pyziak, 2017; Luboiński and Markowicz, 2017; Maria John et al., 2015). When considering these factors, it is imperative that further governmental decisions favored environment, certified non-GMO soya products and implemented good agricultural practices.

This research was based on the results of an experiment carried out in the Variety Assessment Experimental Station of Głubczyce in the years 2015-2017.

2. Materials and methods

The field experiment was carried out from 2015 to 2017 on arable land in Głubczyce (Variety Assessment Experimental Station, soil valuation class II, complex of agricultural usefulness 1) as a strict two-factor experiment (nitrogen fertilizer; soya variety), on Cambisol with texture of silt loam (granulometric composition consisting of particles of ∅ in mm: >2=0.5%; 2-0.05 =12%; 0.05-0.002=70%; <0.02=50%; <0.002=18%) and neutral pH (6.6-6.8).

A non-GMO soya variety was used (Table 1). The soybeans were inoculated with Nitragina Puławska or Hi Stick Soy containing live *Bradyrhizobium* bacteria which through the plants bind nitrogen from the air in the soil (the minimal level of live *Bradyrhizobium japonicum* bacteria was $2x10^9$).

Table 1. Varieties and their origin

No.	Variety	Year of entry in the Polish National Registration	Year of entry in the Variety Recommendation List	Origin	Representative in Poland
1	Augusta	2002		PL	Uniwersytet Przyrodniczy Poznań
2	Mavka	2013	2016	UA	Hodowla Soi Agro Youmis Polska sp. z o.o. Poznań
3	Aligator	2015	2017	FR	Euralis Nasiona sp. z o.o., Poznań
4	Lissabon		2016	AT	Saatbau Polska sp. z o.o. Środa Śląska

Source: COBORU (2017).

For each growing season, before sowing, ammonium nitrate (0, 30, 60 kg N/ha) was applied. The soya (*Glycine max* (L.)Merrill) was planted on the optimal dates for Głubczyce and when the weather conditions were favorable: April 28, 2015, April 25, 2016 and May 8, 2017.

Agro-technical treatments were adapted according to the Institute of Plant Protection (IOR, 2012) recommendations, and the soil and weather conditions. The forecrop was winter wheat. Harvesting was done at soya maturity: August 8, 2015 – Augusta; September 14, 2015 - Mavka, Aligator, Lissabon; Sept. 8, 2016 Augusta; September 15, 2016 – Mavka; September 23, 2016 - Aligator, Lissabon; September 1, 2017 – Augusta; September 9, 2017 – Mavka; September 14, 2017 - Aligator, Lissabon.

After harvesting, at 15% soybeans moisture, the yield was determined (dt/ha) as MTS – the mass of 1,000 seeds according to PN-R- 65950, total protein (in % of dissolved matter) according to PN 75/A-04018, raw fat (in % of dissolved matter) according to Randall with Sozhlet's modification (PN76/R- 64753). Based on the same base as above, the yield of protein and fat were calculated in dt/ha. The standard was taken to be the mean of all the varieties in a given season in VAES in Głubczyce. Each analysis (harvesting and chemical) were made by co-autor Marta Bednarczyk for COBORU project.

The results were analyzed statistically using the analysis of variance. The lowest significant differences (LSD) were calculated based on the t-Tukey test at the significance level of p=0.05.

3. Results and discussion

The principle of developing sustainable agriculture requires rational use of the resources found in the natural environment while – at the same time – increasing production and maintaining an appropriate relationship between ecological, social and economic factors (Wrzaszcz, 2011). It is paradoxical that man can affect the economy and agriculture both positively and negatively. Since he can easily harm the environment in order to meet his own needs, there must be a rational economic-environmental approach to agriculture. Many indices, including integrated ones, have been developed to assess the sustainability of agricultural economy. However, this is not static as it undergoes dynamic changes depending on the degree of diversity of agricultural production, its intensity, how advanced the technology is or the level of agri-technology (Machnacki, 2014). Soya belongs to the legume family, an element of sustainable crops in agriculture, which makes sustainable ecological and economic development possible.

Ecological-agricultural indicators were determined for soya (*Glycine max* (L.) Merrill) cultivation based on selected results registered for the experimental varieties (2015-2017) in the VAES research fields in Głubczyce.

3.1. Ecological-agricultural aspects

The selection of varieties is an important element for determining the yield. It considers agricultural properties, such as fertility, the weight of 1,000 seeds, chemical composition, germination ability and disease resistance. Economically, cultivation of soya can have a positive impact if the climatic conditions in the given region are taken into consideration. Poland's climate and geography restrict possible varieties to those already grown or tested in the country. There are several varieties available from the UE Catalogue, which grow well in Poland's climate. Of these, three are Polish. Opole Voivodship was the first to create a List of Recommended Varieties in 2016 for soya, which included: Aldana, Mavka and Lissabon. In 2017, the list was extended to include: Abelina, Aligator, Lissabon, Merlin, Mavka and Sultan.

Soya is a plant which likes short, warm days. It has a short vegetation period and is very sensitive to drought. For germination the air temperature must be 10-15℃ and that of the soil - 8-10^{o}C. It is genetically adapted to short periods of water shortage. Its greatest water requirements occur during its initial germination, flowering and while forming pods. It reacts negatively to excessive rain during growth.

In Glubczyce, from 2015 to 2017, the mean daily, minimal, maximum and minimal ground temperatures during the soya growing season (May – October) were similar. During the dry year of 2015, only August was clearly warmer. Maximum temperatures occurred in July. However, the total rainfall during this period was lower by 215.6 – 285.0 mm (47 – 56%) than during 2017 and 2016 (Pyziak et al. 2016, 2017; Gawęcki et al. 2018). The total effective temperatures (May 1 – September 30) were clearly higher than the minimum requirement of 1500^{o}C and during individual years was: 2662^{o}C in 2015, 2634^{o}C in 2016 and 2603^{o}C in 2017. The physiological zero for soya is 6^{o}C. Frosts (-0.3 do -3.0^{o}C) have occurred during recent years. As can be seen from scientific research (Luboiński, Markowicz, 2017; Pisulewska et al. 1999) meteorological conditions have a significant effect on both the quantity and quality of soy crops. Our studies confirmed this pattern by showing differences in crop yield (Table 2), the MTS index (Table 3), as well as protein (Table 4) and fat (Table 5) content.

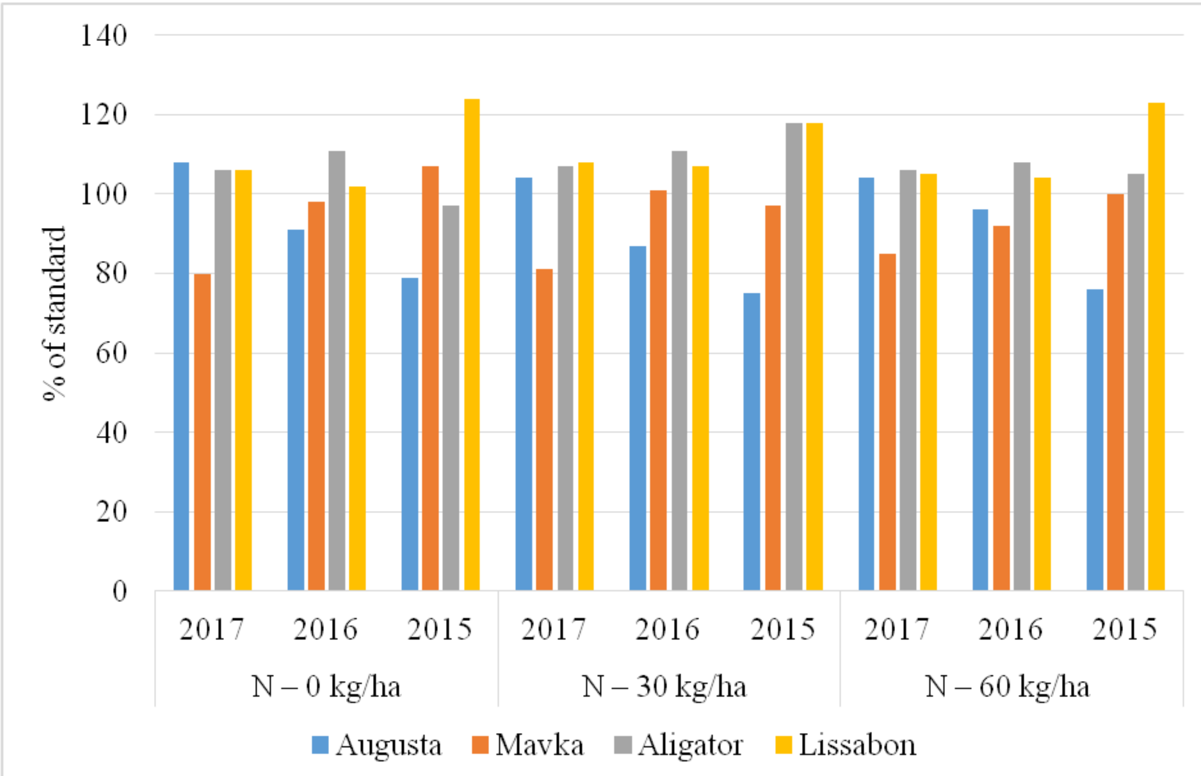
Table 2. Soybean yield [dt/ha] in correlation with the level of nitrogen fertilization

Variety/year	N – 0 kg/ha			N – 30 kg/ha			N – 60 kg/ha		
	2017	2016	2015	2017	2016	2015	2017	2016	2015
standard	34.9	27.6	23.2	37.1	30.4	23.9	36.6	32.7	24.2
Augusta	37.7	25.1	18.3	38.6	26.5	17.9	38.1	31.4	18.4
Mavka	27.9	27.1	24.9	30.1	30.7	23.2	31.1	30.1	24.2
Aligator	37.0	30.6	22.5	39.7	33.7	28.2	38.8	35.3	25.4
Lissabon	37.0	28.2	28.8	40.1	32.5	28.2	38.4	34.0	29.8
LSD between years and fertilization: 3.40 LSD between fertilization in 2017: 3.49 LSD between fertilization in 2016: 2.86 LSD between fertilization in 2015: 3.60 LSD fertilization N – 0 kg/ha: 5.53 LSD fertilization N – 30 kg/ha: 6.16 LSD fertilization N – 60 kg/ha: 5.78									

Source: Autors' own elaboration.

A field study of different varieties showed that the Lissabon variety definitely had higher yields, indicating its high degree of acclimatization to meteorological conditions. The drought of 2015 significantly affected the yield of soybeans, which for the studied varieties averaged 24.07 dt/ha in 2015, in 2016 - 24.07 dt/ha, and in 2017 – 36.21 dt/ha. Soya is sensitive to excessive rain during its vegetative period. Its greatest need for water occurs while germinating, emerging and forming pods. In 2016, there were negative moisture conditions in Głubczyce. The total rainfall in July was 162.4 mm. This was a significant factor causing lower yields than in 2017, which turned out to be the best year for the growth, development and yield of soya. At the same time the seed yield of the studied varieties significantly differed during individual vegetative seasons, as seen by the LSD coefficient (Table 2). The research results clearly show that the quantitative soya yield in an identical environment is modified by weather conditions during the vegetative season and sensitivity of the variety (Figure 1).

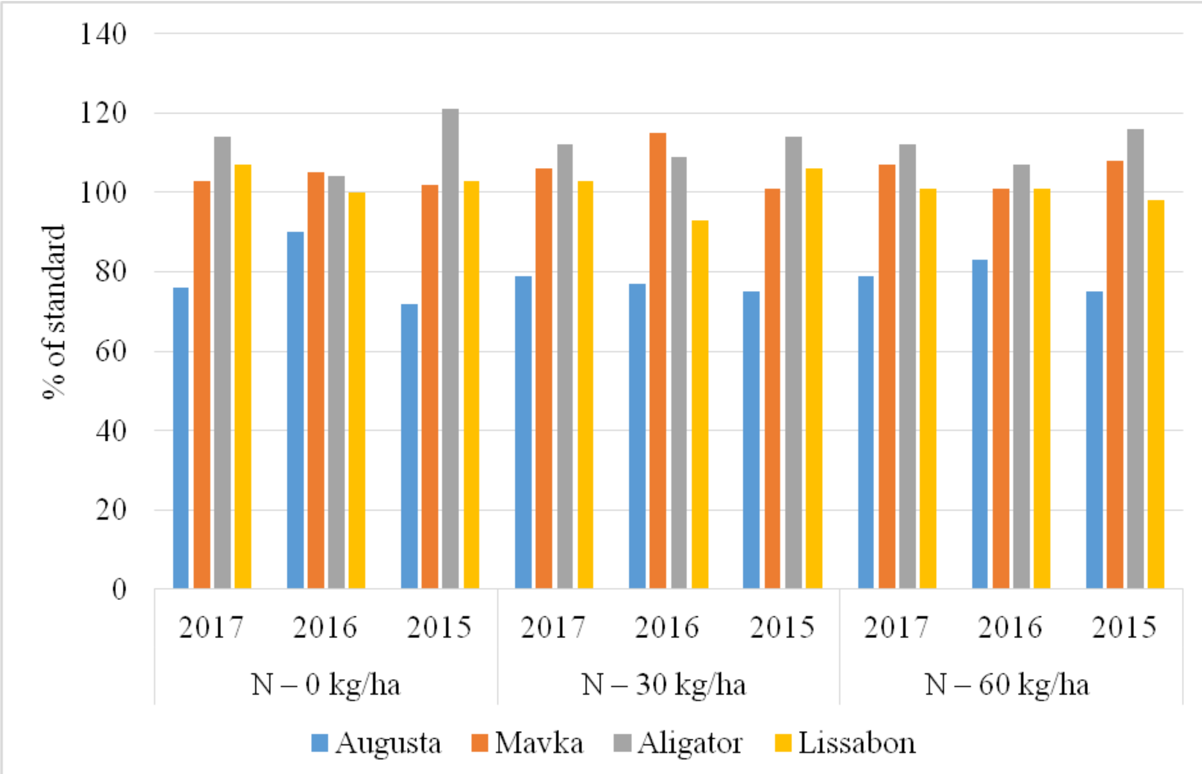
Figure 1. Soybean yield in relationship to the correlation of fertilization. The standard was used as reference



Source: Autors' own elaboration.

MTS is a characteristic of a plant species and variety. According to COBORU (2017) statistics the MTS for the studied varieties were: Augusta - 137 g, Mavka - 180 g, Aligator - 180 g and Lissabon - 160 g. An analysis of these parameters found a close relationship between meteorological conditions during vegetation and the adaptation of each variety to environmental conditions (Table 3, Figure 2).

Figure 2. MTS in relationship to the correlation of fertilization. The standard was used as reference



Source: Autors' own elaboration.

A research experiment on the influence of agrotechnical treatments, including differing nitrogen fertilization on soya yield showed very different results. From the research of Jarecki and Bobrecki (2015), and Pisulewska et al. (1999) it can be seen that 30-60% nitrogen met the nitrogen requirements thanks to symbiosis with *Bradyrhizobium japonicum.* Therefore, the use of mineral nitrogen fertilization in agrotechnics is justified. From the above mentioned research it can be concluded that soy plants using both atmospheric and mineral nitrogen have greater yields than when only one form of nitrogen is absorbed. However, the use of high doses of nitrogen can inhibit the absorbance of atmospheric nitrogen. Increasing the doses of mineral nitrogen significantly raises crop yield and the MTS (Tables 2 and 3).

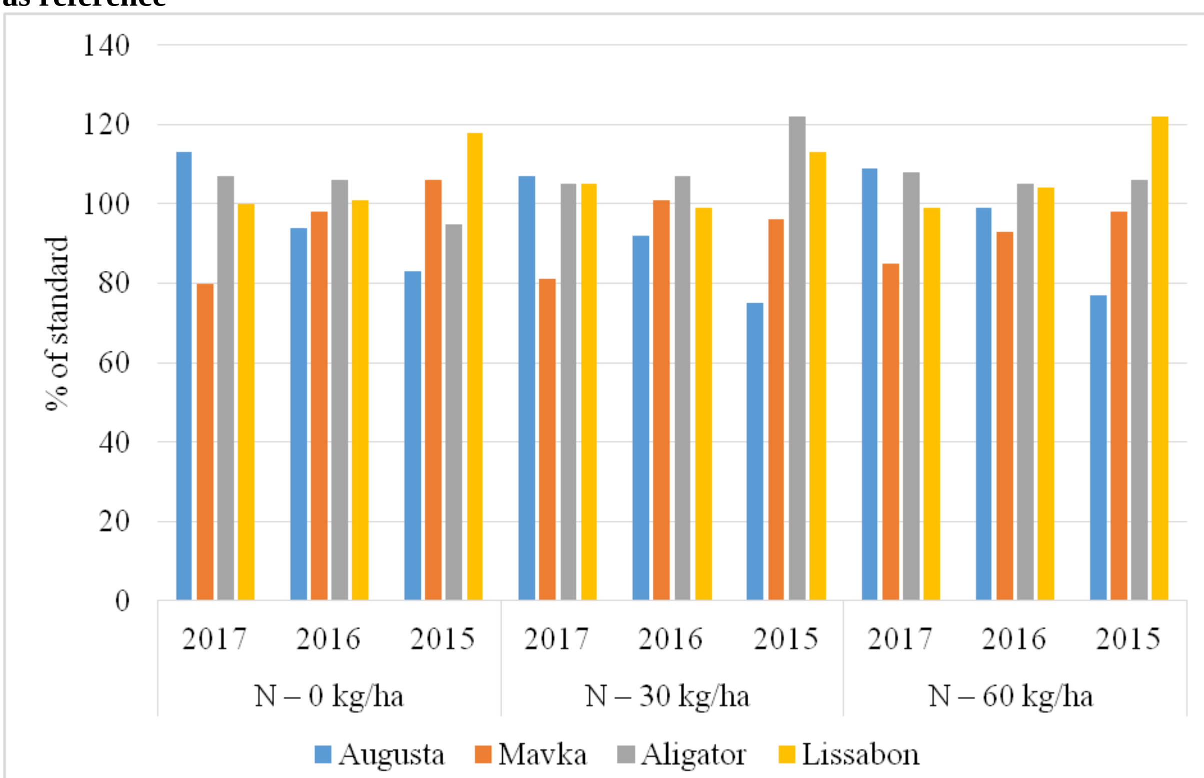
Table 3. The mass of 1,000 seeds in correlation with nitrogen fertilization

Variety/year	N – 0 kg/ha			N – 30 kg/ha			N – 60 kg/ha		
	2017	2016	2015	2017	2016	2015	2017	2016	2015
standard	191.0	175.5	156.2	187.6	175.3	161.8	186.6	176.4	173.6
Augusta	145.7	157.2	112.9	147.9	134.7	120.8	147.9	146.5	129.3
Mavka	196.3	183.4	159.6	199.0	201.9	163.3	200.4	177.7	187.1
Aligator	216.7	181.7	189.4	210.0	190.6	183.9	209.9	188.5	201.5
Lissabon	205.1	174.8	160.3	193.5	163.7	172.0	188.1	178.9	170.6
LSD between years and fertilization: 13.49 LSD between fertilization in 2017: 22.06 LSD between fertilization in 2016: 16.44 LSD between fertilization in 2015: 24.14 LSD fertilization N – 0 kg/ha: 24.87 LSD fertilization N – 30 kg/ha: 24.31 LSD fertilization N – 60 kg/ha: 21.03									

Source: Autors' own elaboration.

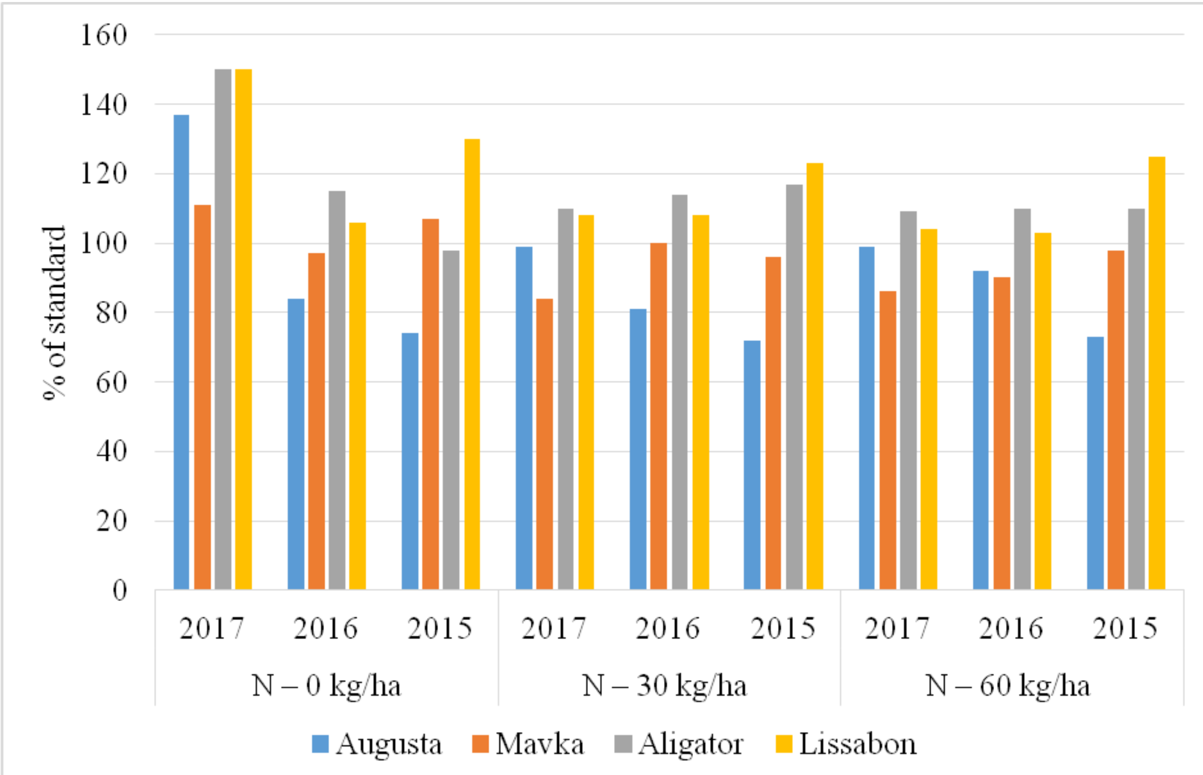
This relationship has been confirmed by many years of scientific research in VAES in Głubczyce. Simultaneously, the highest dose of nitrogen lowered the biological value of soybeans as seen by the protein (Figure 3) and fat values (Figure 4) in the beans as well as the LSD coefficient between nitrogen combinations.

Figure 3. Protein yield in relation to the correlation of fertilization. The standard was used as reference



Source: Autors' own elaboration.

Figure 4. Fat yield in relation to the correlation of fertilization. The standard was used as reference



Source: Autors' own elaboration.

There was a significantly negative relationship between nitrogen fertilizer and the fat content of soybeans. Higher doses of nitrogen significantly lowered its content in the beans of all varieties and in all analyzed periods (Table 4).

Table 4. Fat yield [dt/ha] in correlation with nitrogen yield

Variety/year	**N – 0 kg/ha**			**N – 30 kg/ha**			**N – 60 kg/ha**		
	2017	**2016**	**2015**	**2017**	**2016**	**2015**	**2017**	**2016**	**2015**
standard	5.4	6.3	7.4	7.9	7.1	5.3	7.8	7.5	5.1
Augusta	7.4	5.3	5.5	7.8	5.8	3.8	7.7	6.9	3.7
Mayka	6.0	6.1	7.9	6.6	7.1	5.1	6.7	6.8	5.0
Aligator	8.1	7.2	7.3	8.7	8.1	6.2	8.5	8.3	5.6
Lissabon	8.1	6.7	9.6	8.5	7.7	6.5	8.1	7.7	6.4
LSD between years and fertilization: 0.73									

LSD between fertilization in 2017: 0.92 LSD between fertilization in 2016: 0.81 LSD between fertilization in 2015: 1.50 LSD fertilization N – 0 kg/ha: 1.16 LSD fertilization N – 30 kg/ha: 1.33 LSD fertilization N – 60 kg/ha: 1.33

Source: Autors' own elaboration.

Some studies have shown that 25-30 kgN/ha is the most effective dose and increases soybean yield as well as protein value (Lorenc-Kozik, Pisulewska, 2003; Penna et al., 2011). This relationship was confirmed by Piezło and Bobreckiej-Jamro (1996), and Penna et al. (2011). In the study of Pisulewska et al. (1999), the same relationship was not found. Their research found that the greater the nitrogen dose (60 kg/ha), the greater the yield, which was not statistically significantly greater than the best yield variety Lissabon. Overall, a dose of 30 kgN/ha gave the best results for all four varieties. Nitrogen fertilizer increased the protein content of the beans of all varieties in comparison to 0 kg N/ha. The differences in protein values with 30 kgN/ha or 60kgN/ha were not statistically significant as seen by the LSD values (Table 5).

Table 5. Protein yield [dt/ha] in correlation with nitrogen fertilization

Variety/year	**N – 0 kg/ha**			**N – 30 kg/ha**			**N – 60 kg/ha**		
	2017	**2016**	**2015**	**2017**	**2016**	**2015**	**2017**	**2016**	**2015**
standard	13.8	8.8	8.4	15.0	9.4	9.3	14.8	10.3	10.2
Augusta	15.6	8.3	7.0	16.1	8.6	7.0	16.1	10.2	7.9
Mavka	11.0	8.6	8.9	12.2	9.5	8.9	12.6	9.6	10.0
Aligator	14.8	9.3	8.0	15.8	10.1	11.3	16.0	10.8	10.8
Lissabon	13.8	8.9	9.9	15.7	9.3	10.5	14.6	10.7	12.4
LSD between years and fertilization: 1.55 LSD between fertilization in 2017: 1.49 LSD between fertilization in 2016: 0.75 LSD between fertilization in 2015: 1.49 LSD fertilization N – 0 kg/ha: 2.65 LSD fertilization N – 30 kg/ha: 2.89 LSD fertilization N – 60 kg/ha: 2.39									

Source: Autors' own elaboration.

This agrees with Penna et al. (2011). There was a significant relationship between 30 kgN/ha and fat content of the seeds (Table 4). A similar relationship was seen by Luboński and Markiewicz (2017) in the VAES soil of Głubczyce. Therefore it can be stated that the best fertilizer variant for soya (*Glycine max* (L.)Merrill) under the climate and in the habitat of

Głubczyce is a starting dose of 30 kgN/ha. Aligator and Lissabon (Figures 1-4) had the greatest yield with the best yield parameters (protein and fat content, MTS).

3.2. Economic aspects

The efficiency of soya cultivation involves chemical and biological cycles. In such a cultivation system using mineral fertilizers should be adjusted to the biological habitat, primarily with respect to economic production and, secondly, the analyzed parameters – environment quality (Adesemoye and Kloepper, 2009). Soy plants use both mineral and atmospheric nitrogen thanks to symbiosis with *Bradyrhizobiaceae* bacteria. Another very significant element in soya production is its very important role in the crop rotation of seeds which thus improves economic production (Dobek 2006).

According to the research carried out in VAES in Głubczyce (Pyziak, Bednarczyk, 2017), the most important environmental advantages of soya cultivation include the enrichment of grain crop rotation by adding approximately 0.35t/ha of organic material and 50-80 kg N/ha for the successive plants. Furthermore, 4-5 times less water is used in relation to the primary crops, and fertilization with P, K and Mg can be limited or eliminated altogether (with the necessary soil composition). Very small doses or no nitrogen fertilization, the limited use of pesticides, especially fungicides, insecticides and regulators are both economically and environmentally profitable. An additional, very significant element in soya production is its important role in crop rotation of grains. It can increase the yields of grains (Dobek 2006), and thus affect the economics of production.

Based on calculations of the research results (2015-2017) conducted at the Experimental Station in Głubczyce, with the same costs and demand for soya it is profitable to produce soya as can be seen in Table 6.

Table 6. Economic index of soy production using: 0, 30 and 60 kg N/ha (without subsidies) assuming fixed costs of ammonium nitrate at 2430 PLN/ha, 2496 PLN/ha and 2562 PLN/ha

Variety/year	2017			2016			2015		
	N–0 kg/ha	N–30 kg/ha	N–60 kg/ha	N–0 kg/ha	N–30 kg/ha	N–60 kg/ha	N–0 kg/ha	N–30 kg/ha	N–60 kg/ha
standard	2805	3069	2928	1710	2064	2343	1050	1089	1068
Augusta	3225	3294	3153	1335	1479	2148	315	189	198
Mavka	1750	2019	2103	1635	2109	1953	1350	984	1068

Aligator	3120	3459	3258	2160	2559	2733	945	1734	1248
Lissabon	3120	3519	3198	1800	2379	2538	1890	1734	1908

Source: Autors' own elaboration.

The economic coefficient of production clearly shows that it is determined by production conditions and the variety used when the price of soya is fixed. Economically the year 2017 was the most profitable in the cultivation of all the studied varieties. The profitability index of production indicated that the Lissabon and Aligator varieties are the most suited to the production conditions in Głubczyce. Particularly advantageous in the production of soy is the fact that it does not require high input expenses, especially with good agricultural practices. It needs limited amounts of fertilizer and does not require chemical protection against diseases and pests or bean drying. Particularly important economically in soya production is financial subsidizing which is received for protein rich plants intended for animal feed. With this in mind pro-environmental decisions made by the government must be made, including certification of non-GMO soy production and good agricultural practices.

4. Conclusions

All the analyzed parameters significantly affect the quantity and quality of crops as well as economic aspects. Weather conditions during individual vegetation periods significantly affect all the analyzed parameters involved in the quantity and quality of crop structure, as well as economic ones. The best weather was recorded in 2017 and during that year there were the highest yields in terms of both quantity and quality. The drought of 2015 significantly affected the soya yield which averaged 24.07 dt/ha. In 2016 and 2017, the crop yields were significantly higher with mean values of 30.39 dt/ha and 36.21 dt/ha. The studied varieties differed in various environments with different starting amounts of nitrogen fertilizer. The most effective dose of nitrogen was 30 k/ha, which significantly increased the quality parameters: MTS, protein and fat contents.

Consequently, with the weather conditions existing in the area of Głubczyce and in its environs, Aligator and Lissabon gave the highest yields at all the nitrogen doses. Taking into consideration complete subsidizing and the resulting influence of soya cultivation, cultivation of soya in Głubczyce, with its meteorological and soil conditions, soy production is justified. It can also show positive economic aspects of sustainable farming.

Acknowledgments
The authors wish to thank the management of COBORU for their willingness to publish the results of variety studies carried out on the VAES area of Głubczyce. We also thank Dalia Gosik, a native speaker, for proofreading.

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Zrównoważenie środowiskowe w produkcji soi w oparciu o wyniki badań polowych przeprowadzonych w stacji doświadczalnej oceny odmian w Głubczycach w latach 2015-2017

Streszczenie

Celem przeprowadzonych badań była ocena wpływu zmiennego systemu nawożenia azotem w uprawie soi, na cechy jakościowe i ilościowe struktury plonów oraz aspekt ekonomiczny jako istotne elementy zrównoważonego gospodarowania w rolnictwie.

W pracy wykorzystano wyniki doświadczeń ścisłych prowadzonych w Stacji Doświadczalnej Oceny Odmian w Głubczycach w latach 2015-2017. W badaniach porównano plony nasion, białka i tłuszczu w czterech odmianach soi (*Glycine max* (L.)Merrill) non-GMO (Augusta, Mavka, Aligator, Lissabon) w zależności od zróżnicowania azotem w dawkach 0, 30 i 60 kg N/ha, oraz oszacowano opłacalność produkcji w/w wariantach nawozowych. Plony nasion porównywanych odmian soi różniły się istotnie wskazując jednocześnie na bardzo wysoką zależność składu ilościowego i jakościowego od przebiegu warunków pogodowych w okresie wegetacji. Nawożenie azotem w dawce 30kg N/ha okazało się optymalną dawką tego składnika w uprawie soi zarówno w aspekcie jakościowo-ilościowym struktury plonu jak i w aspekcie ekonomicznym. Najlepiej przystosowaną odmianą soi do warunków klimatyczno-siedliskowych rejonu Głubczyc okazały się odmiany Aligator i Lissabon, na co wskazują istotne współczynniki NIR.

Słowa kluczowe: rozwój zrównoważony, soja, non-GMO, nawożenie azotem.