ISSN 1644-0625
ISSN 2300-8504 (online)
www.agricultura.acta.utp.edu.pl

ACTA *Acta Sci. Pol. Agricultura, 14(4) 2015, 81-95*

COMPARISON OF THE DEVELOPMENT AND PRODUCTIVITY OF SOYBEAN (*Glycine max* (L.) MERR.) CULTIVATED IN WESTERN POLAND

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Abstract. In the growing season 2014, yield and chemical composition of soybean cv. Merlin was studied in three localities in western Poland. Seeds dressed with Hi Stick Soybean™ inoculant (Saatbau®) in Fix Fertig system were sown at the sowing density of 70 germinating seeds per 1 m^2. Agroclimatic conditions in the growing season of soybean in particular localities were highly diversified, mainly in the amount and distribution of rainfall. In the flowering stage (BBCH 69), soybean plants in Grodziec Śląski reached the highest weight. In further development stages, plants in Kołbacz had the highest weight of vegetative and generative parts (seeds and pod shells). In this locality, in the green maturity stage (BBCH 79) and full maturity stage (BBCH 89) soybean stand reached a biomass of approx. 5 $Mg \cdot ha^{-1}$. Diversified production potential of soybean was determined by plant height which affected weight of a single plant. Higher plants had a greater number of pods and seeds. Correlation between pod length and its weight in the full maturity stage was moderate (R^2 = 0.52). Chemical composition of soybean seeds indicated significant diversification between localities. Seeds in Grodziec Śląski had a higher total protein content. Seed yield in soybean depended on agroclimatic conditions, thus in Kołbacz, Pawłowice, Grodziec Śląski it was: 2.65, 1.55, 2.55 $Mg \cdot ha^{-1}$, respectively. The lowest level of yield in soybean in Pawłowice (central part of Poland) resulted from the occurrence of flooding stress in early growth stages and long-term (June – August) drought in the summer.

Key words: chemical composition of seeds, flooding stress, morphological traits, pod traits

INTRODUCTION

Currently, worldwide, soybean is the most important protein source for people and animals [Fenta *et al*. 2014]. Greater proportion of soybean in the sowing structure is

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a significant and at the same time desirable change in the moderate climate zone [Vollmann *et al*. 2000]. A significant factor of this tendency is a prompt increase in the area for fabaceae cultivation, especially soybean, as a protein source for people and animals on the one hand, and on the other hand increase in the area of good forecrops for cereals in Poland [Pyziak 2013, Szukała 2014]. It is stated in literature that post--harvest residues, aboveground- and underground weight of legumes, and especially soybean, provide 50-200 $kg \cdot ha^{-1}$ of organic nitrogen [Powers and McSorley 2000]. A set of beneficial functional traits of soybean as an oilseed-protein plant is a significant reason to increase area for the cultivation of early cultivars [Pyziak 2013]. There is a common agreement that a better satisfaction of requirements of animal production for plant protein may be realized both through cultivation of species and cultivars of indigenous legume plants, and new soybean cultivars (non-genetically modified) of a high production potential, for whose cultivation there is social acceptance and economic justification [Pyziak 2013]. According to Szukała [2014], there is an urgent need to increase the area of fabaceae cultivation in the country (legumes) up to approx. 500,000 ha (i.e. by over 300,000 ha) compared to the area of legume plants cultivation in 2013 (173,000 ha), which enables to satisfy the needs for feed protein in 50%.

Global warming (increase in the mean air temperature in the past 12 years has been statistically proved) makes thermophilous plants behave more and more beneficially with regard to their development and production [Starkel and Kundzewicz 2008]. The existing situation may affect increase in the yield of numerous thermophilous plants (grape-vine, soybean, maize) by 20-60% [Kozyra and Górski 2004, Szwejkowski *et al*. 2008]. Since the beginning of the 21^{st} century, increase in the mean air temperature has been observed, being $0.02^{o}C \cdot year^{-1}$ [Żmudzka 2009]. The continuously progressing increase in the air temperature enables to introduce soybean into cultivation in Poland on a larger scale. At present, possibility to spread soybean cultivation more widely in the moderate climate of Europe (from the Alps north) should be attributed to global warming and society's objection to GMO cultivars, as a hitherto prevailing protein source in feeds, obtained from soybean meal from import. In the moderate climate of Europe, soybean, currently and in the future, may be an important crop species, of a high economic significance.

Soybean very strongly responds to the level of agronomic factors, especially to initial nitrogen dose [Lorenc-Kozik and Pisulewska 2003], height of phosphorus and potassium doses, and also to fertilization with microelements [Ziółek and Ziółek 1987, Jasińska and Kotecki 1994]. Nutritional needs of soybean regarding nitrogen calculated for the production of 1 ton of seeds (+ straw) are approx. 80 kg $N \cdot ha^{-1}$ [Sallvagiotti *et al*. 2008]. Thus, with the planned seed yield on the level of 2-3 $Mg \cdot ha^{-1}$, nitrogen intake may be 160-240 kg N per 1 ha. It is estimated that depending on various soil-cultivation conditions, only 50-80% of N is obtained through soybean plants as a result of symbiosis with Rhizobium bacteria [Sallvagiotti *et al*. 2008]. Cultivation experiments carried out in Poland have provided scientific justification for taking up cultivation of early soybean cultivars „000" and „00", whose growing season lasts 120-130 days [Nawracała 2008, Pyziak 2013]. Despite extensive theoretical knowledge, both of Polish [Jasińska and Kotecki 1987, Pyzik *et al*. 1987, Bobrecka-Jamro *et al*. 1995] and foreign origin [Vollmann *et al*. 2000, De Bruin and Pedersen 2008, Malik *et al*. 2011, Valinejad *et al*. 2013, Fenta *et al*. 2014], only verification of productivity of soybean cultivars under country's production conditions may provide reliable answers, useful for agricultural science and practice. The aim of the undertaken research under production conditions of the warmer western part of Poland, was analysis of generative development, morphological traits of soybean plants and pods, as well as of yield and chemical composition of the seeds.

MATERIAL AND METHODS

In the growing season of 2014, observations and measurements of soybean plants were conducted under production conditions in three localities in western Poland. Fields of soybean cv. Merlin (Saatbau®), were localized in three voivodeships: West Pomeranian, Greater Poland and Silesian (Fig. 1). The size of production fields at particular Experimental Stations of the Institute of Animal Production (ZZDIZ), was within the range from 3 (Grodziec Śląski) to 6 hectares (Kołbacz). Detailed data describing soil conditions is given in Table 1. Sowing soybean seeds dressed with Hi Stick Soybean™ inoculant (Saatbau®) in Fix Fertig system, was first conducted in Kołbacz (West Pomeranian Voivodeship) on 30th April. Next, on 5th May, soybean was sown in Pawłowice (Greater Poland), and then on 8th May in Grodziec Śląski (Silesian Voivodeship). Soybean was sown at a rate of 70 germinating seeds per 1 m^2, with row spacing of 25 cm. Full emergence was observed after two weeks from sowing. The NPK fertilization and herbicides used to control weed infestation are given in Table 1. It should be highlighted that soil in Kołbacz is highly fertile and contains available forms of: $N_{min.}$ –76.5 kg·ha^{-1}, P_2O_5 – 24.1; K_2O – 37.0; and Mg – 17.1 mg per 100 g of soil. Therefore, in this locality pre-sowing fertilization was omitted. The opposite situation occurred in Pawłowice, where in late autumn manure was applied when sowing of maize was planned. A very good density of the plant stand in Kołbacz excluded the necessity to weed soybean stands.

Fig. 1. Position of localities where evaluation of soybean yield was carried out (Experimental Station of the Institute of Animal Production- PIB (ZZDIZ)

Rys. 1. Rozmieszczenie miejscowości, w których prowadzono ocenę plonowania soi (Zootechniczne Zakłady Doświadczalne Instytutu Zootechniki-PIB (ZZDIZ)

Table 1. Specification of basic agronomical data connected with soybean cultivation under production conditions
Tabela 1. Wyszczególnienie podstawowych danych agrotechnicznych, związanych z uprawą soi w warunkach produkcyjnych

Specification Wyszczególnienie	Locality – Miejscowość		
	Kołbacz	Pawłowice	Grodziec Śląski
Coordinates – Współrzędne	53º18'05''N 14º48'49''E	51º49'49''N 16º45'00''E	49º48'01''N 18º52'04''E
Class of soil – Klasa gleby	IVa	IVb	IIIb
pH	7.4	7.1	6.6
N_{min}, kg·ha^{-1}	76.5	65.8	70.5
P_2O_5, mg·100 g^{-1}	24.1 (b. wysoka – v. high)	14.7 (średnia – medium)	15.5 (wysoka – high)
K_2O, mg·100 g^{-1}	37.0 (b. wysoka – v. high)	19.2 (średnia – medium)	21.3 (średnia – medium)
Mg, mg·100 g^{-1}	17.1 (b. wysoka – v. high)	8.2 (średnia – medium)	7.5 (średnia – medium)
Cultivar – Odmiana		Merlin	
Forecrop – Przedplon	corn kukurydza	sugar beet burak cukrowy	spring wheat pszenica jara
Sowing date – Termin siewu	30.04	05.05	08.05
Sowing density, pcs.·m^{-2} Gęstość siewu, szt.·m^{-2}		70	
Row spacing, cm Rozstawa rzędów		25	
The area of the field, ha Powierzchnia pola	6.0	5.2	3.0
Fertilization – Nawożenie	not applied nie stosowano	manure – obornik 25 t·ha^{-1} + K_2O 60 kg·ha^{-1}	N – 18 kg·ha^{-1}, P_2O_5 – 46 kg·ha^{-1}
Herbicides – Herbicydy	not applied nie stosowano	Harmony 50 SX 8 g·ha^{-1} (26.05 + 12.06) Fusilade Forte 150 EC 0,8 dm^3·ha^{-1} (23.06)	Afalon dyspersyjny 450 SC 1 dm^3·ha^{-1} + Command 400 EC 0,17 dm^3·ha^{-1} (8.05)
Harvest – Zbiór	28.10	07.10	10.10
The beginning of emergence Początek wschodów	15.05	19.05	19.05
Beginning of flowering Początek kwitnienia	18.06	11.07	20.06
Number of days from sowing to harvest Liczba dni od siewu do zbioru	181	155	155

During growth and development of soybean plants, three times in their growing season in the stages of flowering (BBCH 69); green maturity (BBCH 79) and full maturity (BBCH 89), plant samples were collected for biometric analyses. In order to do this, in five places situated along the diagonal of the fields, plants were pulled out from an area of 1 m^2. In case of fields of an area greater than 3 ha, the number of measurements was increased by 1 when calculated per each additional hectare. On the soybean plants collected in the mentioned development stages, biomass of the aboveground part (dry weight) as well as weight of particular plant parts (stems, leaves, flowers, pods, seeds) was determined. The obtained data was used to estimate share of plant parts in the yield of the aboveground biomass of soybean stand and of a single plant. In the stages of green and full maturity, detailed biometric measurements of plants and pods were carried out on 10 plants randomly selected from each sample. The following traits were determined: plant height, height of the first pod position, pod number per plant, and seed weight per plant. Moreover, harvest index was estimated in the stages of green and full maturity of soybean, and was calculated as a ratio of the seed yield from the collected samples to the aboveground biomass. The pod harvest index was calculated according to the formula [Fenta *et al*. 2014]:

$$\mathrm{PHI} = \frac{\text{Seed biomass dry weight at harvest}}{\text{Pod biomass dry weight at harvest}} \times 100$$

Seed harvest was carried out with the use of a combine harvester in the full maturity stage, and the precise dates of harvest are presented in Table 1. After harvest, seed moisture was determined with the oven-drying method. In the paper, the seed yield is given calculated for normative moisture of 14%. The content of total protein, crude fiber, crude fat and ash was determined using near infrared reflectance spectroscopy (NIRS) with InfraXact™ analyzer (Foss®). The content of nitrogen-free extract was calculated from the difference. The yield of total protein and crude fat was calculated based on the dry weight of seed yield and the content of seed components. The obtained data was subjected to statistical analysis using Statistica® package (data analysis software system), version 10, while significance of differences was evaluated with Tukey's test on the significance level of $P = 0.05$.

RESULTS

Agroclimatic conditions in particular localities were highly differentiated in soybean's growing season (Fig. 2). In Pawłowice at the end of April, there occurred rainfall after which sowing was carried out. Directly after sowing, again there occurred rainfall resulting in a decrease in soil moisture, while on some parts of the field there occurred stagnant water. Under these conditions, there occurred stress of seed flooding, as a result of which some seeds decayed. In this locality, further soybean growth continued under conditions of heavy atmospheric and soil drought. This reduced growth of soybean plants, and consequently resulted in a lower weight of a single plant, and also in a decrease in the aboveground biomass per unit of area. In other localities, soybean development was normal. Relatively high rainfall in Kołbacz and Grodziec Śląski occurred in August, which favorably affected development of soybean seeds, and as a consequence it influenced high values of the harvest index.

Figure 3 presents proportion of particular plant parts in the total dry weight of soybean plant in three generative development stages. In the flowering stage (BBCH 69) the highest dry weight was observed in soybean plants from Grodziec Śląski. On the other hand, the most advanced in their development soybean plants were found in Kołbacz. In this locality, on the first and second whorl of flowers there were pods in the initial stage. Acceleration of the development of soybean in Kołbacz was especially visible in the green maturity stage (BBCH 79). Soybean plants had a higher total aboveground biomass than in other localities. Soybean growing in Kołbacz exceeded in its weight plants from Grodziec Śląski, although in the flowering stage (BBCH 69), plants in this locality obtained the highest weight. Also, pod weight (seeds and pod shells) of soybean plants from Kołbacz was the highest. It should be highlighted that soybean cultivated in Pawłowice, throughout the whole growing season produced plants of the lowest dry weight.

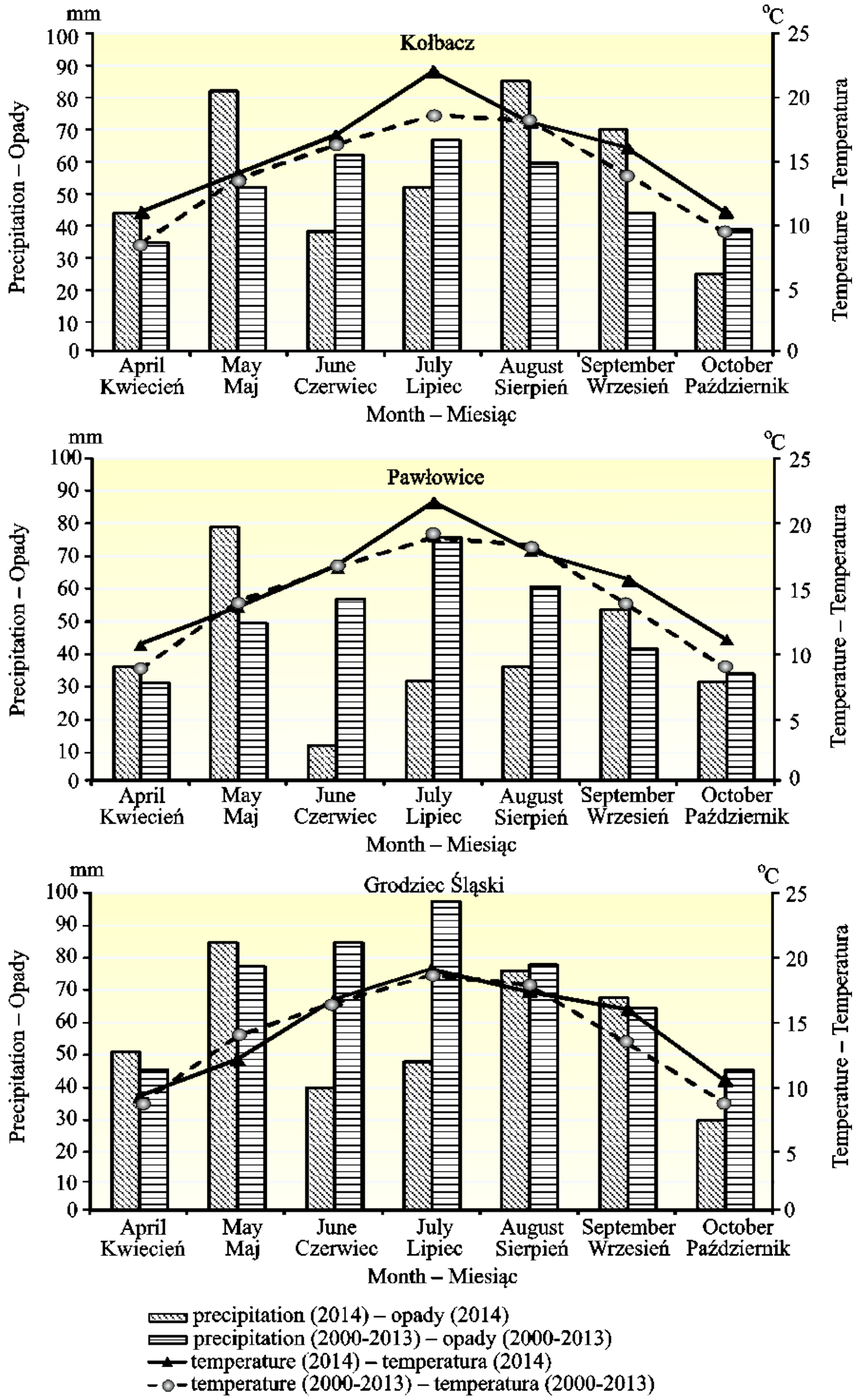

Fig. 2. Weather conditions in the months of soybean's growing season
Rys. 2. Przebieg pogody w miesiącach wegetacji soi

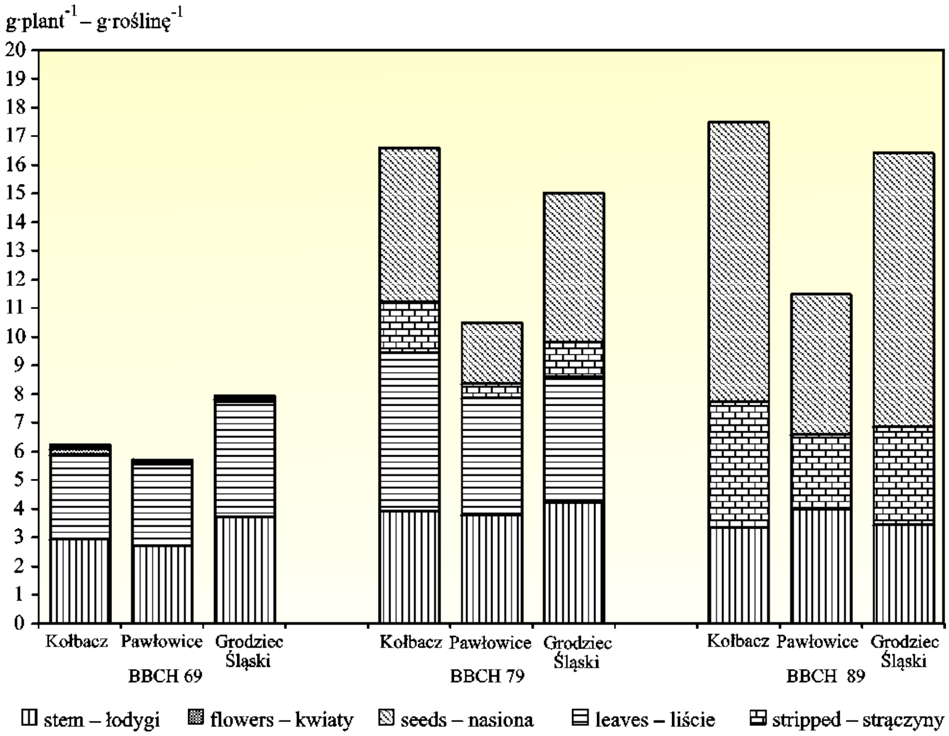

Fig. 3. Formation of dry matter components in a single soybean plant depending on the growth stage and locality

Rys. 3. Kształtowanie się elementów składowych suchej masy pojedynczej rośliny soi w zależności od fazy rozwojowej i miejscowości

Dynamics of changes in the biomass of soybean stand, compared with the aboveground parts per unit area is given in Figure 4. A significant increase in the biomass of soybean stand occurred between the stages of flowering (BBCH 69) and green maturity (BBCH 79). In the green maturity stage, mostly the yield of the aboveground soybean biomass was established. Along with soybean plant maturation, number of leaves decreased in the weight of the aboveground plant parts, while weight of seeds and pod shells increased. In Kołbacz in the full maturity stage (BBCH 89), soybean stand reached the biomass of 5.23 $Mg \cdot ha^{-1}$. Lower by 0.32 $Mg \cdot ha^{-1}$ aboveground biomass was produced by soybean in Grodziec Śląski. Only in Pawłowice, the yield level of the aboveground biomass per unit of area was significantly lower and amounted to 3.44 $Mg \cdot ha^{-1}$.

The tallest soybean plants were developed under good habitat conditions in Kołbacz, which mean the highest weight of a single plant (Table 2). Taller soybean plants had a higher number of pods and seeds, and a higher seed weight per plant (on average 10.4 g). However, a single soybean plant in Pawłowice gave the yield on the level of approx. 5 g. A single soybean plant developed on average about 20 pods for the localities. In Kołbacz, in the full maturity stage, pod number per single plant was 25.3, which was significantly higher, by 5.7 pods, compared with Pawłowice. Harvest index of soybean stand was high, and for Kołbacz and Grodziec Śląski it remained identical. A significantly lowest value of this index was observed in Pawłowice.

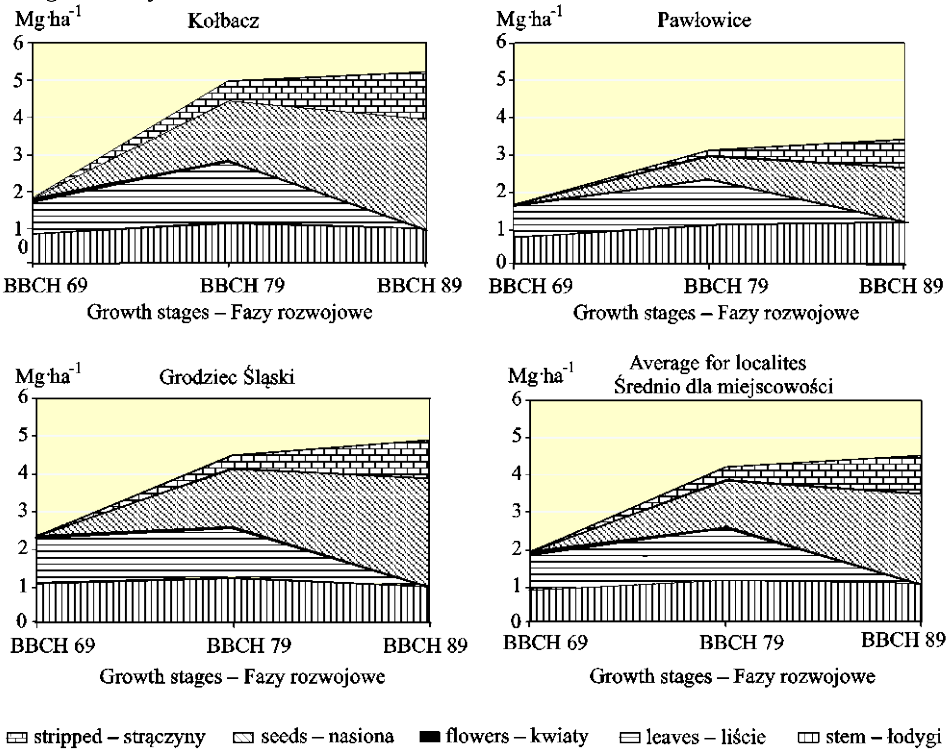

Fig. 4. Proportion of particular plant parts in the yield of the aboveground biomass of soybean stand depending on the growth stage and locality

Rys. 4. Udział w plonie nadziemnej suchej biomasy łanu soi poszczególnych części roślin w zależności od fazy rozwojowej i miejscowości

Soybean pods did not differ significantly in length and weight, which was estimated in the full maturity stage of the plants (Table 3). Compared with Pawłowice, a significantly higher seed weight per pod and significantly the highest pod index, being 0.74 $g \cdot g^{-1}$, in soybean was observed in Grodziec Śląski. However, weight of a single seed in the experimental localities was on a similar level. Only soybean pods from Grodziec Śląski indicated tendencies towards a higher seed number in single fruits. In the green maturity stage, index of soybean pod in the studied localities was on the same level. However, higher rainfall in the foothill village Grodziec Śląski, located in the region Cieszyn Silesia (Silesian Voivodeship), contributed to variation in this index in the full maturity stage. Higher rainfall enabled a more intensive seed development in maturity stage, which slightly increased weight of a single seed. At the same time, weight of pod shells in Grodziec Śląski was significantly lower compared with pod shells from Pawłowice.

Table 2. Characteristics of soybean plants in two maturity stages depending on the locality
Tabela 2. Charakterystyka roślin soi w dwóch fazach dojrzewania w zależności od lokalizacji

Trait – Cecha	Growth stage BBCH Faza rozwojowa	Locality – Miejscowość			$LSD_{0.05}$ $NIR_{0,05}$	ρ value poziom ρ
		Kołbacz	Pawłowice	Grodziec Śląski		
Plant weight, g	79*	16.57	10.48	15.01	4.083	0.002
Masa rośliny	89*	18.35	11.79	15.50	3.724	< 0.001
Plant height, cm	79	78.0	51.0	78.5	7.72	< 0.001
Wysokość rośliny	89	80.0	50.7	76.7	5.58	< 0.001
Number of pods, pcs.	79	35.2	9.73	23.3	6.48	< 0.001
Liczba strąków, szt.	89	25.33	19.60	20.81	5.52	0.036
Seed weight, g	79	5.34	2.13	5.21	1.592	< 0.001
Masa nasion	89	10.40	4.90	8.96	1.971	< 0.001
Harvest index, $g \cdot g^{-1}$	79	0.31	0.20	0.35	0.056	< 0.001
Współczynnik plonowania	89	0.57	0.41	0.57	0.023	< 0.001

*79 – green maturity – dojrzałość zielona, *89 – full maturity – dojrzałość pełna

The height of the 1st pod position on the stem depended on habitat conditions in the locality. The highest position of the first whorl of soybean pods on the stem was observed in Grodziec Śląski, which resulted from a quicker rate of plant development before reaching flowering stage, in which soybean plants were characterized by a higher weight of a single plant. In Pawłowice and Kołbacz, soybean developed pods on the first whorl lower by 1.8 and 5.2 cm, respectively (Table 3).

Table 3. Formation of morphological traits of soybean pods depending on the plant's growth stage and habitat conditions (locality)
Tabela 3. Kształtowanie się cech morfologicznych strąków soi w zależności od fazy rozwojowej roślin i warunków siedliskowych (miejscowości)

Trait – Cecha	Growth stage BBCH Faza rozwojowa	Locality – Miejscowość			$LSD_{0.05}$ $NIR_{0,05}$	ρ value poziom ρ
		Kołbacz	Pawłowice	Grodziec Śląski		
Pod lenght, cm	79*	4.35	4.14	4.43	0.246	0.018
Długość strąka	89*	4.40	4.42	4.47	ns – ni	0.807
Pod weight, g	79	0.61	0.42	0.44	0.075	< 0.001
Masa strąka	89	0.68	0.67	0.72	ns – ni	0.465
Seeds weight per pod, g	79	0.39	0.27	0.28	0.061	< 0.001
Masa nasion w strąku	89	0.48	0.44	0.53	0.075	0.027
Stripped mass, g	79	0.22	0.15	0.16	0.023	< 0.001
Masa strączyny	89	0.20	0.22	0.19	0.029	0.012
Pod harvest index, $g \cdot g^{-1}$	79	0.63	0.63	0.63	ns – ni	0.985
Indeks strąka	89	0.70	0.66	0.74	0.027	< 0.001
Number of seeds per pod, pcs.	79	2.79	2.45	2.79	0.325	0.021
Liczba nasion w strąku, szt.	89	2.82	2.67	3.00	ns – ni	0.081
Single seed weight, g	79	0.14	0.11	0.10	0.017	< 0.001
Masa 1 nasienia	89	0.17	0.17	0.18	ns – ni	0.450
Height of 1st pod position, cm Wysokość osadzenia 1. strąka	89	7.27	10.73	12.50	2.56	< 0.001

*79 – green maturity – dojrzałość zielona, *89 – full maturity – dojrzałość pełna
ns – ni – non-significant differences – różnice nieistotne

Regression of the four pairs of traits of soybean pods are given in Figure 5. Between pod length and weight (Fig. 5a) the dependence had a linear character, and depended on the phase of maturity stage. In the green maturity stage, correlation of this pair of traits was low, only 20% of the variation in the pod weight was determined by variation in its length. At the end of vegetation, after establishing the final seed weight, the dependence was significantly higher, 52% of the variation in the dependent variable (pod weight) was determined by the independent variable (pod length). The most visible linear dependences occurred between pod length and seed number. In Figure 5c for full maturity stage (end of soybean's growing season) the estimated coefficient of determination (R^2) was 0.57. Length of a soybean pod with seed weight in the full maturity stage (BBCH 89) also indicated a linear dependence (Fig. 5b). In this case, 42% of variation in the seed weight per pod was determined by pod length. Pod length turned out to be a trait not very useful in explaining variation in the pod index (Fig. 5d).

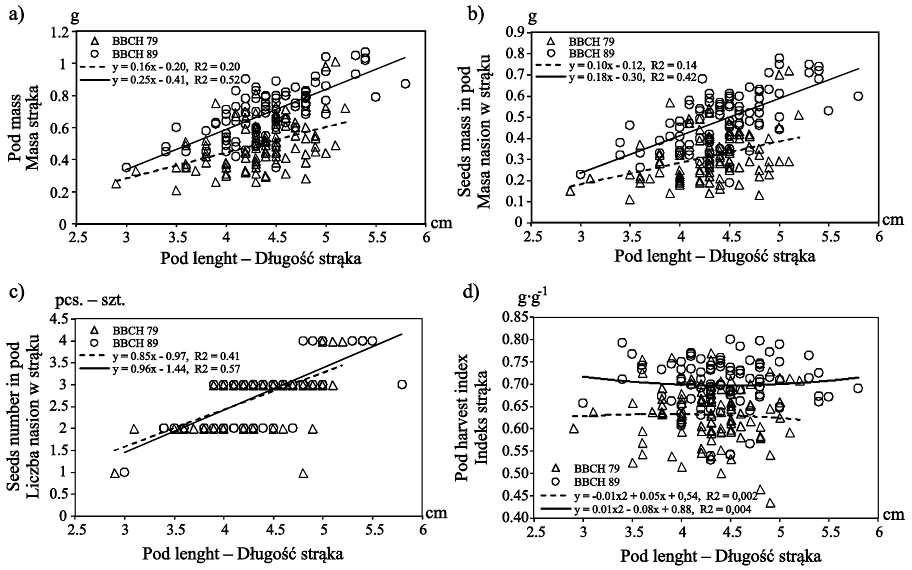

Fig. 5. Correlations between the four pairs of traits of soybean pods
Rys. 5. Współzależności dla czterech par cech strąków soi

Chemical composition of seeds indicated significant variation between localities (Table 4). A higher total protein content was found in soybean seeds collected in Grodziec Śląski. A negative correlation between the content of protein and fat can be observed in soybean seeds. More crude fat and less total protein was contained in soybean seeds obtained in northern (Kołbacz) and central (Pawłowice) part of Poland. However, soybean seeds harvested under conditions of southern Poland (Grodziec Śląski) were characterized by a lower content of crude fiber.

The yield of soybean seeds was significantly the lowest in Pawłowice, which was affected by a poorer development of plants and stand in the growing season, mainly resulting from excess of water at the beginning of soybean's growing season, and then its long-term deficit. Better productivity of single plants in Kołbacz and Grodziec Ślaski, was reflected in a higher seed yield per unit of area (Table 5). In these localities, also the yield of basic nutrients, such as crude fat and total protein, was significantly higher compared with Pawłowice.

Table 4. Chemical composition of soybean seeds depending on the growth stage and locality, $g \cdot kg^{-1}$ d.m.
Tabela 4. Skład chemiczny nasion soi w zależności od fazy rozwojowej i miejscowości, $g \cdot kg^{-1}$ s.m.

Component – Składnik	Growth stage BBCH Faza rozwojowa	Locality – Miejscowość			$LSD_{0.05}$ $NIR_{0,05}$	ρ value poziom ρ
		Kołbacz	Pawłowice	Grodziec Śląski		
Total protein	79*	348.2	346.4	360.3	1.81	< 0.001
Białko ogółem	89*	339.7	333.3	362.6	2.03	< 0.001
Crude fat	79	187.7	205.7	189.9	3.70	< 0.001
Tłuszcz surowy	89	216.8	230.4	208.8	1.86	< 0.001
Nitrogen-free extract	79	351.1	333.4	341.9	2.73	< 0.001
Związki bezazotowe wyciągowe	89	330.9	320.7	323.1	3.70	< 0.001
Crude fiber	79	50.1	49.6	44.6	1.71	< 0.001
Włókno surowe	89	50.1	53.3	44.2	1.86	< 0.001
Ash	79	63.0	64.9	63.4	1.52	0.015
Popiół	89	62.5	62.3	61.2	ns – ni	0.164

*79 – green maturity – dojrzałość zielona, *89 – full maturity – dojrzałość pełna
ns – ni – non-significant difference – różnica nieistotna

Table 5. Soybean yield and basic components depending on locality
Tabela 5. Plonowanie soi i zbiór podstawowych składników pokarmowych w zależności od miejscowości

Specification Wyszczególnienie	Locality – Miejscowość			$LSD_{0.05}$ $NIR_{0,05}$	ρ value poziom ρ
	Kołbacz	Pawłowice	Grodziec Śląski		
Seed yield, $Mg \cdot ha^{-1}$ Plon nasion	2.65	1.55	2.55	0.278	< 0.001
The yield of crude fat, $kg \cdot ha^{-1}$ Plon tłuszczu	488.4	303.6	452.8	52.2	< 0.001
Total protein yield, $kg \cdot ha^{-1}$ Plon białka	765.3	439.1	785.9	82.1	< 0.001

DISCUSSION

The results presented in this paper indicate a possibility to cultivate an early soybean cv. 'Merlin' under production conditions of the western part of Poland. Under production conditions, it was beneficially reflected in the productivity of a single plant and in the yield of the aboveground biomass per unit area. The determinant of a good yield was a proper development of soybean plants, which is testified by weight of a single plant and of the aboveground biomass of the stand. Bury and Nawracała [2004], highlight a great influence of weather conditions on the use of the yield-producing potential of soybean under conditions of West Pomerania, where with decreasing amounts of monthly rainfall the seed yields also decreased. In our research, a significant influence was indicated of rainfall on the development of soybean plants. This effect was especially visible in Pawłowice, as high amount of rainfall before sowing soybean seed as well as after this treatment caused flooding stress. As a consequence of occurring the stress situation, growth in early development stages of the plant slowed down. Negative effect of this stress was decay of some of the sown soybean seeds, which caused decrease in the plant density, and as a consequence the production potential decreased with reference to a single plant and stand (area). The studies of Henshaw [2005], carried out under subtropical conditions of Florida, indicate that starting with the 37th day from the date of sowing soybean, plants flooded in the stage of early development (flooding stress) formed a significantly smaller leaf area. Soybean response to flooding stress results in a decrease in leaf area of a single plant and of a stand [Bacanamwo and Purcell 1999], and also in reduction of the leaf number and their weight [Linkemer *et al*. 1998]. Empirical data obtained by Henshaw [2005] indicated that occurrence of flooding stress in the stage of emergence causes in the early development stages reduction in the weight of plant components, especially of leaves, and also a lower plant height. However, it is highlighted that soybean is considered to be a crop plant which tolerates flooding stress [Sullivan *et al*. 2001] more than Chinese long beans (*Vigna unguiculata* ssp. *sesquipedalis*). Fenta *et al*. [2014] found that phenotypic traits of the root system in three soybean cultivars growing under conditions of drought or irrigation in south Africa, are an easy marker under field conditions for indicating genotypical differences between sensitive cultivars and those tolerating drought stress. Further in the growing season, development of soybean plant and stand in Pawłowice was reduced by a long-term three--month soil drought, which occurred with strong intensity in the period from June to August. Drought in the growing season of soybean causes stomatal closure and reduction in the yield, which drops along with the duration of drought period and its intensity [Frederick *et al*. 1991]. In our research in Kołbacz, as a consequence of good soil moisture, we observed occurrence of a quick soybean growth in the early development stages of the plants which quickly covered rows and developed a large leaf area, which reduced development of weeds in the stand, and thus we could abandon the use of herbicides. This shows the possibility to cultivate soybean with low expenditure, especially when agrochemical indicators of the soil are favorable. In other localities, rainfall in August was similar to rainfall in the long-term period and was (mm) for Kołbacz – 85; and for Grodziec Śląski – 77, which ensured good development of pods and seeds in the maturity stage. Tanaka and Shiraiwa [2009] indicated that cultivars of two utterly different types of soybean lines, determinate and indeterminate, had a variable leaf area, without a possibility to indicate prevalence of either of them. Measurements of 10 traits of soybean plants carried out in Pakistan by Malik *et al*. [2011] on 92 cultivars indicated that the range for each of them is wide. An average height of soybean plants was 68.1 cm, while the range was from 41.4 to 106.4 cm. Regardless of the type of soybean cultivar, decrease in the plant height of this species is pursued in cultivating new creations [Radhakrishnan and Ranjitha Kumari 2008]. Authors of these studies obtained lines of soybean plants in the full maturity stage of a height of 53.8 cm, compared with the height of 123.4 cm which was characteristic of parental plants. However, in these studies, lower offspring plants (self-cloning lines) had shorter pods (3.32 cm), which caused a lower seed weight per fruit (0.092 g). In the present study, soybean cv. 'Merlin' developed pods with a lower seed weight (from 0.33 to 0.61 g), which was the result of worse climatic conditions of the moderate climate of Poland compared with the subtropical climate of India.

In 2014, soybean cultivated under production conditions indicated a high production potential, though typical for early cultivars of this species. In the compared localities, at the end of the growing season, yield of the dry weight of a single soybean plant oscillated from 6.0 to 21.8 g, which was the result of the effect of habitat conditions, as well as of weather course in the months of the growing season. Under more favorable agroclimatic conditions of the northern and southern part of Poland, represented by Kołbacz and Grodziec Śląski, soybean development was normal, which resulted in a high productivity of a single plant as well as its stand, and consequently in a good yield. Harvest index of soybean stand estimated for plants in their full maturity stage (harvest yield) at a rate of 0.57 g g^{-1}, was highly beneficial from the agricultural point of view. The results of the present study indicate that soybean plants cv. 'Merlin' are sensitive to both excess and deficiency in rainfall in the growing season. In other studies, reduction in the seed yield was higher as it was from 20 to 93% as a result of a 2- and 6-day flooding [Sullivan *et al*. 2001].

The results of our study indicated that higher content of total protein, 360.3 (g·kg^{-1}), was found in soybean seeds harvested in Grodziec Śląski with the most favorable thermal and rainfall conditions for soybean. Under European conditions, soybean will be treated as a source of protein for animals, which is obtained from cultivars without genetic modifications. In the present study, this component was harvested at the amount of 411.2 to 827.6 kg·ha^{-1}. Determinants of the yield of total protein in soybean per unit area were seed yield and content of this component in the seeds. This tendency visibly manifested itself in the present study in Pawłowice and Grodziec Śląski, which had utterly different agroclimatic conditions in 2014. Vollmann *et al*. [2000] while comparing 60 soybean genotypes of a shorter growing season, obtained a high protein content in the seeds (within the range of 399-476 g·kg^{-1}), which was only possible with high air temperature (warmer years) but with moderate rainfall. Under conditions of soil drought (hot years without rainfall) there occurred a significant decrease in the protein content in the seeds (within the range of 265-347 g·kg^{-1}”).

CONCLUSIONS

1. Habitat conditions, including mainly amount and distribution of rainfall, determined soybean's development and its production potential. The highest yields were obtained in Kołbacz and Grodziec Śląski: 2.65 and 2.55 Mg·ha^{-1}, respectively. In Pawłowice, flooding stress in May caused stand thinning in some areas of the field, while rainfall deficiency in the successive three months of vegetation significantly reduced seed weight per plant, which resulted in a low yield level, being only 1.55 Mg·ha^{-1}.
2. Soybean pods collected from three different localities did not differ significantly in length, weight, seed number per pod, nor weight of 1 seed estimated in the full maturity stage of the plant, which testifies to the fact that these traits only to a slight degree are liable to the effect of habitat conditions.
3. Chemical composition of soybean seeds indicated significant variation between localities. A higher content of total protein and less crude fiber was found in soybean seeds harvested in the conditions of south-west Poland.

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PORÓWNANIE ROZWOJU I PRODUKCYJNOŚCI ROŚLIN SOI (*Glycine max* (L.) MERR.) UPRAWIANEJ W ZACHODNIM PASIE POLSKI

Streszczenie. W sezonie wegetacyjnym 2014 r. w trzech miejscowościach położonych w zachodniej części Polski badano plonowanie i skład chemiczny soi odmiany Merlin. Wysiewano nasiona zaprawione szczepionką Hi Stick Soybean™, firmy Saatbau® w systemie Fix Fertig, w obsadzie 70 szt. kiełkujących nasion na 1 m^2. Warunki agroklimatyczne w czasie wegetacji soi w poszczególnych miejscowościach były silnie zróżnicowane, głównie ilość i rozkład opadów. W fazie kwitnienia (BBCH 69) najwyższą masę miały rośliny soi w miejscowości Grodziec Śląski. W dalszych fazach rozwojowych najwyższą masę części wegetatywnych i generatywnych (nasion i strączyn) miały rośliny w miejscowości Kołbacz. W tej miejscowości w fazach dojrzałości zielonej (BBCH 79) i pełnej (BBCH 89) łan soi uzyskał biomasę ok. 5 $Mg \cdot ha^{-1}$. Zróżnicowany potencjał produkcyjny soi był determinowany wysokością roślin, która decydowała o masie pojedynczej rośliny. Wyższe rośliny miały większą liczbę strąków i nasion. Współzależność pomiędzy długością strąka a jego masą w fazie dojrzałości pełnej była umiarkowana (R^2 = 0,52). Skład chemiczny nasion soi wykazywał istotne zróżnicowanie pomiędzy miejscowościami. Wyższą zawartość białka ogółem zawierały nasiona z miejscowości Grodziec Śląski. Plon nasion soi był zależny od warunków agroklimatycznych i wynosił w miejscowościach: Kołbacz, Pawłowice, Grodziec Śląski odpowiednio: 2.65, 1.55, 2.55 $Mg \cdot ha^{-1}$. Najniższy poziom plonowania soi w Pawłowicach (środkowa części Polski) wynikał z wystąpienia stresu zatopienia we wczesnych fazach rozwojowych i długotrwałej (czerwiec – sierpień) suszy w okresie lata.

Słowa kluczowe: cechy morfologiczne, cechy strąka, skład chemiczny nasion, stres zatopienia

Accepted for print – Zaakceptowano do druku: 29.07.2015

For citation – Do cytowania:

Śliwa, J., Zając, T., Oleksy, A., Klimek-Kopyra, A., Lorenc-Kozik, A., Kulig, B. (2015). Comparison of the development and productivity of soybean (*Glycine max* (L.) Merr.) cultivated in western Poland. Acta Sci. Pol. Agricultura, 14(4), 81-95.