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Effect of soybean cultivars sowing dates on seed yield and its correlation with yield parameters

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Abstract: The article presents the effect of three sowing dates on the growth, development and yielding of four soybean cultivars of different earliness and under different temperature and precipitation conditions across the years. The seed yield from early sowing significantly correlated with the total precipitation in June and July, and at later dates, also with the total precipitation in August. The significantly highest soybean yields were collected from the sowing at a turn of April and May, and the highest seed and protein yield, as well as protein content in seed, were recorded for the mid-early Merlin cultivar. Neither the number and the seed weight per pod nor the 1 000-seed weight significantly depended on the sowing date. Over years, a significant, almost linear decrease in the plant height and the first pod setting height, the weight of nodules, the protein yield and the LAI (leaf area index) value was observed. High significant correlations were found between the seed yield and the plant height and the first pod setting height, as well as between the seed number and the seed weight per pod and the 1 000-seed weight as well as between the plant height and the first pod setting height.

Keywords: *Glycine max* (L.) Merr.; sowing time effect; weather conditions; plant morphology and productivity

Circa over the recent dozen years, there has been observed some interest in soybean cultivation at a larger scale in Central and Eastern Europe, especially in the Danube region, the area most favourable to soybean growing in Europe (Dima 2016). In that relatively new soybean region, the research is necessary to determine the effect of environmental variation and cultivation technology, especially the date of sowing, on soybean growth, development and yielding. However, only four countries, Italy, France, Romania and Serbia, record continuously growing seed yields (Bastidas et al. 2008), and it is estimated that even 20% (of about 2.4 million ha) of the soybean imports can be replaced by its cultivation in Eastern Europe.

One of the most important soybean cultivation conditions is the earliness of the cultivars grown as plant development, and ripening is closely related to the day length. It is commonly believed that in Europe, it is possible to grow soybean wherever the growing season is 105–140 days long, namely the cultivars with 000, 00 and 0 earliness, which means that the total temperature required for the growing season should range from 1 500 °C to 1 800 °C (Berschneider 2016). The key soybean plantations in Europe are found at 47–48° of north latitude (Miladinovic et al. 2006), while Poland is located at 49°00'N to 54°50'N. The analysis of the changes in weather parameters in Poland points to the shortening of the active soybean growth, prolonging the time the soil heats up to 8 °C at a depth of 5 cm, and to the occurrence of weather and agricultural droughts as well as late-spring ground frosts (Zarski et al. 2019).

The optimal soybean sowing date is an important factor affecting the plant growth and yield, and it changes depending on the climate conditions and the accompanying reactions of cultivars to the day length (Bastidas et al. 2008, Sincik et al. 2011).

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An earlier sowing date stands for a longer period of vegetative and generative development as the soybean seed yield is positively correlated with the length of flowering, pod setting and seed-filling stages (Egli and Bruening 2000). In the north of Germany (Balko et al. 2014), higher yields recorded for late-maturing cultivars were observed for the years with higher total temperature, while more stable yet lower yields were recorded for early cultivars. The soybean seed yield decreases with a delay in the sowing date after May 1 (Licht and Huffman 2017). Many authors (Hu and Wiatrak 2012, Jaybhay et al. 2019) found a negative impact of delayed sowing date on soybean growth and development, especially under unfavourable humidity conditions.

Next to the cultivar earliness, the soybean yielding in Europe, similarly as in other countries, is much affected by water deficit, which essentially shortens both the vegetative and generative stage and thus lowers the yield (Desclaux and Roumet 1996). For that reason, under Poland's climate conditions, soybean sowing is recommended for the turn of April and May (Boros et al. 2019) when the soil temperature reaches 8 °C.

The aim of the research has been to evaluate the effect of the sowing date and the earliness of four selected soybean cultivars available in Europe/Poland on their yielding and the morphological parameters of plants and structural yield components.

MATERIAL AND METHODS

Site description. The research of the effect of the sowing date on the yielding of selected soybean cultivars was performed in 2016–2019 at 53°13' of north latitude and 17°51' of east longitude for 89.8 m a.s.l. The research involved four soybean cultivars with various earliness; very early Annushka (0000) – 115–125 days of vegetation, early Aldana (000) – 125–130 days of vegetation, mid-early Merlin (000++) – 127–132 days of vegetation and late Lissabon (000) – 133–140 days of vegetation, sown at 3 sowing dates: early (19–24/4), medium (29/4–8/5) and delayed (9–15/5). The soil type classified according to the WRB as Haplic Luvisols (Cutanic) was a typical lessive soil formed with light loamy sand, deposited in a shallow layer on light loam (IUSS WRB 2015). The content of phosphorus was very high (90 mg/kg of soil), potassium high (134.25 mg/kg of soil), magnesium low (28.75 mg/kg of soil). The content of available forms of potassium and phosphorus was assayed with the Egner-Rhiem DL method and magnesium with the Schachtschabel method. The content of nitrate and ammonium ions was determined with colorimetric tests with the Behelot and Griess-Ilosvay reactions. The soil pH was potentiometrically measured in 1 mol/L KCL. In all the research years, the soil pH was adequate for soybean cultivation (Table 1).

The experiment forecrop in all the years were cereals; 60 kg P and 80 kg K kg/ha, as well as 30 kg N/ha, were applied before sowing; after each sowing Sencor (0.55 L/ha) and after emergence Fusilade Forte (0.8 L/ha) were applied. The plots for sowing were 21.24 m^2 in size, and the plots for harvest 20.0 m^2, row spacing was 16 cm, and the sowing rate was 90 germinating seeds per 1 m^2, and sowing depth 3–5 cm. Right prior to sowing, the sowing material was inoculated with HiStick Soy® (BASF Agricultural Specialities Limited, UK).

In the vegetation period in 2016 and 2017, the plant vegetation in June, July and August occurred at an average temperature of 17.6 °C; however, already in the successive two years, it was considerably higher (18.6 °C) (Figure 1). A high and well-distributed total rainfall was recorded in June and July 2016 (98.8 mm and 133.8 mm) and in 2017 (118.9 mm and 126.1 mm), which facilitated plant growth, development and yielding of soybean cultivars. However, the successive research years recorded soil drought; in 2018, there was noted an almost one-time rainfall of

Table 1. Chemical properties of soil prior to soybean sowing in 2017–2019

Year	P	K	Mg	NO_3-N	NH_4-N	pH_{KCl}
	(mg/kg of soil in 0–60 cm)			(mg/kg in dry matter in 0–60 cm)		
2016	109.0	127	30.0	9.53	5.73	6.3
2017	92.0	149	31.0	5.90	7.96	6.3
2018	82.0	112	27.0	6.12	6.97	6.8
2019	77.0	149	27.0	8.69	2.27	6.5
Mean	90.0	134	28.7	7.56	5.73	6.5

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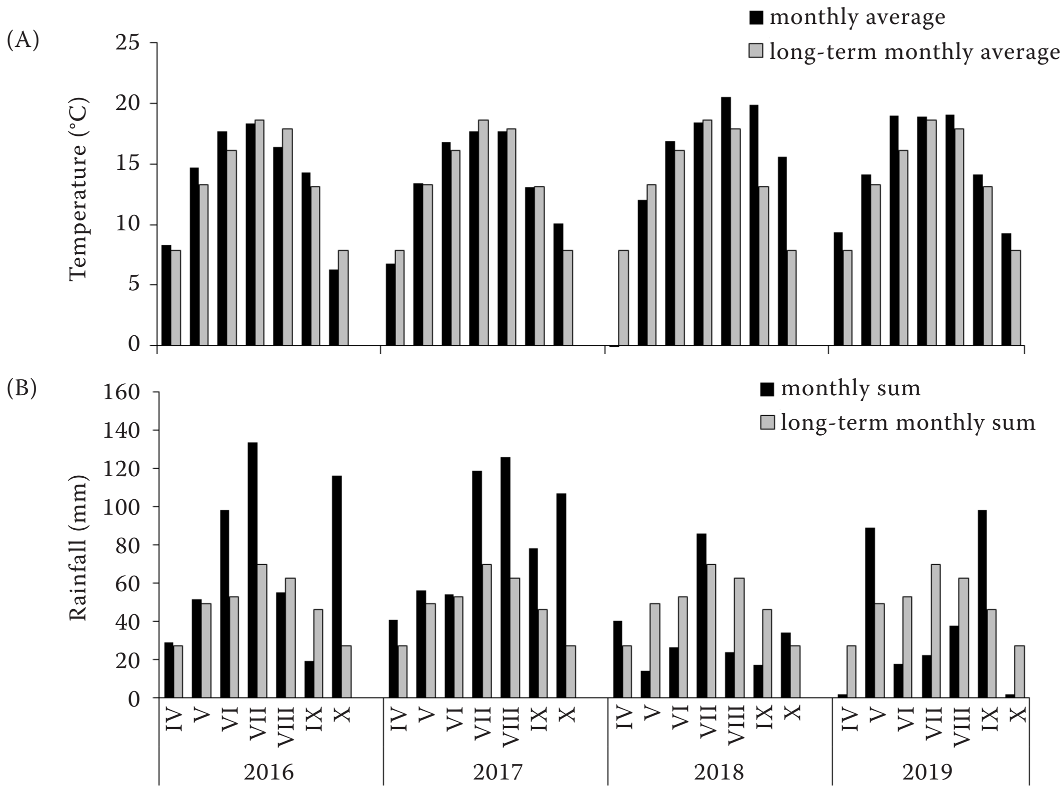

Figure 1. Temperature (A) and rainfall (B) at the site of the field experiment

86 mm in July and 23.7 mm in August, and in 2019 only 22.4 mm and 37.7 mm, respectively. The rainfall in September in those years no longer affected the soybean yielding. The pods and the seeds in 2017 and especially in 2019 with high total rainfall in September were drying slowly, considerably prolonging the vegetation period, on average to about 140–145 days, irrespective of the cultivar.

Plant development monitoring. At the full flowering stage, the SunScan Canopy Analysis System (ΔT Devices Ltd., Cambridge, UK) was used to determine the LAI (leaf area index – m^2/m^2). At the same time, the weight of the nodules from ten plants of each plot was specified. Right before harvest, the number of pods per plant, the number of seeds per pod, the seed weight per pod and the 1 000-seed weight, as well as the plant height and the first pod setting height, were provided. Also, the yield of the dry weight of straw from each plot was assessed to calculate the HI value (the seed yield in the total weight of plants before harvesting in %).

Data analysis methods. The experiment involved two factors in a completely randomised block design in four replications. The data was processed with ANOVA, using Statistica, version 10 (StatSoft, Tulsa, USA). The *LSD* (least significant difference) test at $P < 0.05$ was used for the difference between the parameter means. The $P < 0.05$, $P < 0.01$ and $P < 0.001$ were significant. The Pearson correlation coefficients were used for the dependence between the parameters. Also, the regression analysis was used to account for the relationship between some parameters, especially the seed yield (SY) and its components. The means in the tables and the charts provided with the same letters do not differ significantly.

RESULTS AND DISCUSSION

Soybean seed yield and yield components. Europe's optimal soybean sowing date falls within a broad range; mid-April through mid-May (Dima et al. 2016); however, a delay in the sowing day after May 1 most often results in a linear decrease in the seed yield (Benatti et al. 1990, Licht and Huffman 2017, Egli and Bruening 2020). An especially negative effect of a delayed sowing date is observed for the years with unfavourable humidity conditions (Hu and Wiatrak 2012, Jaybhay et al. 2019). In the northern part of Germany, higher soybean yields in late cultivars were observed only at higher total

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temperature; however, the yields of earlier cultivars were more stable and lower. Hence an early soybean sowing date in a given region is necessary for using the biological plant potential (Bastidas et al. 2008, Sincik et al. 2011). The second important condition for soybean yielding is the rainfall total and distribution. Dolijanovic et al. (2013) found that during growth and development, the soybean plants require 500 mm of rainfall, including at least 300 mm during flowering and fruit-bearing, with the seed yield mostly depending on the total rainfall in May, July and August (Mandic et al. 2017). In the present research, the average soybean seed yield decreased significantly, almost linearly, with a decrease in the total rainfall in the successive research years by 22% in 2017, by 56% in 2018, and as much as by 74% in 2019, as compared with the 2016 yield (Table 2), mostly due to a considerable shortening of both the vegetative and generative stages (Desclaux and Roumet 1996). Hence, the four-year average soybean seed yield was average, and it amounted to 2.51 t/ha, whereas the highest yield was recorded for cv. Merlin (3.17 t/ha) and the lowest – for cv. Aldana (1.91 t/ha). The significantly highest multi-year soybean yield (2.63 t/ha) was reported for sowing at the turn of April and May, similarly as reported in the experiments of the domestic (Boros et al. 2016) and European authors (Benatti et al. 1990, Bastidas et al. 2008, Egli and Bruening 2020). Interestingly, except for a significantly variable number of pods per plant, the other values of structural soybean yielding components did not depend on the sowing date significantly. According to Hu and Wiatrak (2012), the unfavourable humidity conditions not only decrease the vegetative soybean plant growth but mostly increase the abortion of flowers and pods, which, in the present research, resulted in a shortened seed filling and decreased the number of seeds per pod, the seed weight and thousand seed weight. The analysis of variance has also shown the most significant interactions between the factors for the seed yield and HI value, and much less for the other soybean parameters under study.

Table 2. Seed yield, harvest index value as well as yield components in four soybean cultivars at early, medium and the late date of sowing in 2016–2019

		Seed yield (t/ha)	Harvest index	Number of pods per plant	Number of seeds per pod	Weight of seeds per pod (g)	Thousand seed weight (g)
Year (Y)	2016	4.04[a]	49.8[ab]	22.8[ab]	2.01[a]	0.356[a]	176[a]
	2017	3.14[b]	50.9[a]	25.0[a]	1.96[a]	0.354[a]	183[a]
	2018	1.79[c]	48.4[b]	15.1[d]	1.58[c]	0.243[c]	151[c]
	2019	1.06[d]	51.4[a]	21.2[c]	1.85[b]	0.300[b]	163[b]
Sowing date (S)	early	2.40[c]	47.4[c]	18.5[b]	1.87	0.356	176
	medium	2.63[a]	52.4[a]	21.2[a]	1.81	0.354	183
	late	2.50[b]	50.6[b]	23.3[a]	1.86	0.243	151
Cultivar Cv)	Annushka	2.53[b]	47.9[c]	22.3	1.82[ab]	0.300[b]	163[b]
	Aldana	1.91[c]	54.1[a]	19.9	1.73[b]	0.356[a]	176[a]
	Merlin	3.17[a]	51.0[b]	21.9	1.88[ab]	0.354[a]	183[a]
	Lissabon	2.43[b]	47.5[c]	19.9	1.96[a]	0.243[c]	151[c]
Mean		2.51	50.1	21.0	1.85	0.313	168
ANOVA	Y	***	**	***	***	***	***
	S	***	***	***	ns	ns	ns
	Cv	***	***	ns	***	***	***
	Y × S	***	***	***	ns	*	ns
	Y × Cv	***	***	ns	ns	***	***
	S × C	***	ns	ns	ns	ns	**
	Y × S × C	***	***	ns	ns	ns	**

Values of a parameter followed by the same letter did not differ significantly across the years, sowing dates and cultivars (ANOVA followed by Fisher's *LSD* test, $P < 0.05$). ANOVA results: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns – non-significant

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Table 3. Plant height and the first pod setting height, dry nodule weight, protein content and protein yield, as well as the LAI (leaf area index) value in four soybean cultivars at early, medium and late sowing dates across the years

		Plant height (cm)	First pod setting height (cm)	Dry nodule weight (g)	Protein content (%)	Protein yield (kg/ha)	LAI (m^2/m^2)
Year (Y)	2016	90.0^a	12.8^a	8.08^a	36.8^b	1 540^a	6.13^a
	2017	82.6^b	9.95^b	9.95^b	36.0^b	1 285^b	6.83^a
	2018	38.1^c	7.46^c	7.46^c	32.8^c	580^c	4.21^b
	2019	32.4^d	5.77^c	5.77^d	38.2^a	431^d	2.59^c
Sowing date (S)	early	57.7^b	8.35^b	8.35^b	36.1	868^c	3.94^b
	medium	60.2^b	8.77^b	8.77^b	35.4	1 041^a	4.59^a
	late	64.5^a	9.88^a	9.88^a	36.3	967^b	5.11^a
Cultivar (Cv)	Annushka	71.4^a	11.7^a	11.75^a	34.2^c	948^b	5.06^a
	Aldana	53.2^c	6.97^c	6.97^c	35.7^b	725^c	3.93^b
	Merlin	62.5^b	9.85^b	9.85^b	37.0^a	1 157^a	5.03^a
	Lissabon	56.1^c	7.42^c	7.42^c	36.9^a	1 006^b	4.16^b
Mean		60.8	9.00	8.57	35.9	958	4.69
ANOVA	Y	***	***	***	***	***	***
	S	***	***	**	ns	***	***
	Cv	***	***	ns	***	***	***
	Y × S	***	***	***	*	***	***
	Y × Cv	***	***	ns	***	**	**
	S × C	ns	ns	ns	*	***	***
	Y × S × C	ns	ns	ns	ns	***	***

Values of a parameter followed by the same letter did not differ significantly across the cultivars (ANOVA followed by Fisher's *LSD* test, $P < 0.05$). ANOVA results: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns – non-significant

Morphological plant parameters, LAI value and the protein yield. The successive research years also noted considerable differences in the other soybean parameters (Table 3). According to Czopek and Staniak (2018), water deficit has an unfavourable effect on important, from the practical point of view, morphological soybean plant parameters, especially the plant height and the first pod setting height, which has been very clearly confirmed in the present study. Similarly, as for the yield and the above parameters, also the dry weight of nodules and the protein yield were decreasing linearly together with decreasing total precipitation in successive years. The optimal sowing date resulted in the highest protein yield, which has been confirmed by other research results (Mourtzinis et al. 2017). In Italy, the delay of soybean sowing date from April 4 to July 16 resulted in an increase in the protein content in soybean seeds to over 40% (Benatti et al. 1990, Egli and Bruening 2020). High protein content in seeds largely depends on high temperature and moderate total rainfall over seed filling (Vollmann et al. 2000), which, however, was not observed in the present research, and the protein yield was mostly determined by the total rainfall. Interestingly, a significant decrease was noted in the

Table 4. Pearson correlation coefficients (*r*) for the total rainfall across the months and the seed yield for early, medium and the late date of sowing

Month	Sowing date: early	medium	late
Apr	0.371^{ns}	0.391^{ns}	0.707^{ns}
May	–0.123^{ns}	–0.046^{ns}	–0.372^{ns}
Jun	0.997***	0.975**	0.882^{ns}
Jul	0.867^{ns}	0.874^{ns}	0.990**
Aug	0.368^{ns}	0.533^{ns}	0.567^{ns}
Sep	–0.476^{ns}	–0.340^{ns}	–0.504^{ns}
Jun–Aug	0.824^{ns}	0.914^{ns}	0.828^{ns}
Apr–Sep	0.661^{ns}	0.789^{ns}	0.731^{ns}

**$P < 0.01$; ***$P < 0.001$; ns – non-significant

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Table 5. Correlation matrix (Pearson) between some parameters studied (n = 192)

Soybean parameter	Seed yield	Pod number	Seeds per pod	Seed weight per pod	Thousand seed weight	Plant height
Pod number	0.111^{ns}					
Seeds per pod	0.364**	0.119^{ns}				
Seed weight per pod	0.381**	0.226**	0.735**			
1 000-seed weight	0.191**	0.223**	0.120^{ns}	0.736**		
Plant height	0.820**	0.221*	0.343**	0.318**	0.145*	
First pod height	0.711**	–0.071^{ns}	0.229**	0.033^{ns}	–0.177*	0.784**

$^{*}P < 0.05$; $^{**}P < 0.01$; ns – non-significant

dry weight of nodules in successive research years, which must have been due to a decreasing activity of rhizobia due to extremely unfavourable humidity conditions (Sinclair et al. 1988). Of all the cultivars studied, Annushka showed the significantly highest plant height, dry weight of nodules and LAI value. Merlin gave the highest protein content and yield.

According to Sincik et al. (2011), the dynamics of increasing values of LAI and TDM (total dry matter in V5-R2, R4 and R6) is closely related to soybean yielding, and it depends on the environmental conditions and the sowing date. It is now assumed that the LAI value from 3.5 to 4.0 is the soybean yielding measure, and the later-maturing cultivars are more likely to meet the leaf area requirements and hence they can yield higher than the early cultivars (Holshouser and Withaker 2002), which, however, was not confirmed in the present research.

For respective sowing dates, a strong dependence was found between the total rainfall in June and July and the seed yield; however, the dependence was significant for June at the early and medium dates, whereas for July at the delayed date (Table 4). It was also identified that the soybean yields, irrespective of the sowing date, highly correlated with the total rainfall from June to August and throughout the vegetation period, which is confirmed by high and very high, although non-significant, values of the correlation coefficient (0.661 to 0.914). Mandic et al. (2017) reported the soybean seed yield is significantly positively correlated with the rainfall in May, July and August, whereas Bosnjak (2004) recorded a very high correlation between the seed yield and the total rainfall throughout the soybean vegetation period. Also, Sobko et al. (2020) recorded a positive correlation between the seed yield and the rainfall over flowering – seed filling and maturing when the soybean plants are especially sensitive to water deficit.

According to Wei and Molin (2020), the linear regression models, based on the 1 000-seed weight and the number of seeds per soybean pod, demonstrated low (r = 0.50) and high (r = 0.92), respectively, linear correlations with the seed yield. In the present research, the values were considerably lower, especially for the 1 000-seed weight (Table 5). The seed yield was highest and significantly positively correlated with the plant height and the first pod setting height, which is evident from a very high value of the correlation coefficient, which was also reported by Bateman et al. (2020) for the 1 000-seed weight. As for most of the other parameters, significant correlations with the seed yield were also noted. The correlations between the seed weight per pod with the number of seeds per pod, the thousand seed weight with the seed weight per pod and the first pod setting height with the soybean plant height are also noteworthy.

The regression analysis demonstrates that in the present study, the plant height, the first pod setting height, the 1 000-seed weight, the seed weight per pod and the number of pods per plant can account for 67.2, 50.6, 19.1, 14.5, 13.2 and 0.1% of the soybean seed yield variation, respectively (Table 6). Also, according

Table 6. Regression analysis between the seed yield and some parameters studied

Parameter	Regression equation	R^2
Pod number	$y = 19.0703 + 0.7653 \times x$	0.012
Seeds per pod	$y = 1.6296 + 0.0868 \times x$	0.132
Seed weight per pod	$y = 0.2583 + 0.022 \times x$	0.145
1 000 seed weight	$y = 158.417 + 4.0237 \times x$	0.191
Plant height	$y = 17.2288 + 17.3646 \times x$	0.672
First pod height	$y = 3.7164 + 2.1061 \times x$	0.506

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to Mandic et al. (2020), the number of pods per plant, the seed weight per plant and the thousand seed weight are next to the plant height and the first pod setting height, essential soybean yielding components.

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