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Productivity of Different Soybean Cultivars Depending on Meteorological Conditions and Growing Manner in Latgale 2018–2020

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***Abstract* - In recent decades in Latvia and other European countries increased interest about growing protein-rich crops and especially soybeans (*Glycine max*). Although soybean cultivation experiments in Latvia have been carried out for some time, there is still insufficient knowledge about cultivating these plants in the country's climatic conditions. A field trials was carried out in 2018, 2019 and 2020 in the Latgale Agricultural Science Centre. The effect of three factors (A: soybean cultivar (A1 — 'Lajma', A2 — 'Laulema', A3 — 'Merlin', A4 — 'Tiguan', A5 — 'Paradis', A6 — 'Touttis'); B: sowing rate (B1 — 40, B2 — 50, B3 — 60 germinable seeds per 1 m^2); C: row spacing (C1 — 12.5 cm, C2 — 25 cm) on the development and yield formation of soybean was examined. The experiment was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley varieties in Latvia'. The soybean seed yield was significantly affected by the cultivar ($p < 0.001$) and the sowing rate ($p < 0.01$) in all study years, as well as the meteorological conditions in the specific year affected the yield significantly ($p = 0.012$). In 2018 and 2020, more productive was the cultivar 'Merlin' (3.77 t ha^{-1} and 3.18 t ha^{-1} respectively), but in 2019 the most productive cultivar was 'Paradis' (2.55 t ha^{-1}). Although meteorological conditions during the growing season have a greater impact on the formation of the soybean yield, if it is cool and humid, the soybean vegetation period can be significantly extended, which hinders its ripening and makes harvesting more difficult. Therefore, it is very important to look for earlier cultivars to avoid farming risks.**
Keywords - growing conditions, varieties, Latvia, yield.

INTRODUCTION

Soybean (*Glycine max*) is an important crop, and interest in its importance in a healthy diet is growing every year. Currently, the largest soybean growers are in the United States, South America and China [2]. Attempts to grow soybean in Latvia had already been implemented in the 20th century. The first serious research aimed at supplementing the range of protein-rich plants in Latvia was carried out in the 1980s. [8] Soybeans are considered a warm climate crop, but due to climate change, it could become a valuable crop due to its high protein content. Soybean is one of the most valuable crops in the world as multipurpose crop, as it is also an important source of protein, fibre and fat as well as a feedstock for biofuels [7] Soybean growing areas in the world from 2010 to 2018 have increased from 102.7 million ha, up to 124.9 million ha [4] The area of soybean sowings in Latvia in 2015 was 93.18 ha, but in 2017 it already was 200 ha, but in 2020 it was already 286 ha [1]

Due to climate change and purposeful selection of early, cold-resistant soybean cultivars, soybean cultivation may also become a perspective in the Baltic region [11] The

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growing season of the earlier soybean cultivars lasts 130–140 days, and the rate of soybean development depends to a large extent on air temperature. Soybean is a thermophilic plant, and for its successful cultivation during the growing season the sum of the effective temperature (temperature above +10 °C) must be at least 2000 °C [6] The earliest cultivars are also suitable for cultivation in regions with a lower amount of effective temperatures, and could be perspective for Latvia's conditions. The suitability of cultivars for soybean yield in a particular region depends on their plasticity with changing temperature, as well as reactions to the length of the day at different stages of plant development.

research was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley cultivars in Latvia'.

MATERIALS AND METHODS

A field trials was set up in 2018, 2019 and 2020 in the Latgale Agricultural Science Centre. The effect of three factors (A: soybean cultivar (A1 — 'Lajma', A2 — 'Laulema', A3 — 'Merlin', A4 — 'Tiguan', A5 — 'Paradis', A6 — 'Touttis'); B: sowing rate (B1 — 40, B2 — 50, B3 — 60 germinable seeds per 1 m^2); C: row spacing (C1 — 12.5 cm, C2 — 25 cm) on the development and yield formation of soybean was examined. The experiment was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley cultivars in Latvia'. There was sod podzolized loam (Sm) soil. According to the results of soil analyses performed by State Plant Protection Service of Latvia the soil reaction in 2018 pH KCl was 6.6, organic matter content — 4.1 %, easy K_2O content for plants — 112 mg kg^{-1}, P_2O_5 — 83 mg kg^{-1}, Ca — 223.8 mg kg^{-1}, Mg — 673 mg kg^{-1} and S — < 0.79 mg kg^{-1} and soil reaction in 2019 pH KCl was 6.5, content of organic matter — 2.6%, content of easily usable K_2O for plants — 104 mg kg^{-1}, P_2O_5 — 56 mg kg^{-1}, Ca — 1539 mg kg^{-1}, Mg — 523 mg kg^{-1} and S — <5.9 mg kg^{-1}. Soil reaction in 2020 pH KCl was 6.1, content of organic matter — 3.5%, content of easily usable K_2O for plants — 94 mg kg^{-1}, P_2O_5 — 51 mg kg^{-1}, Ca — 2113 mg kg^{-1}, Mg — 315 mg kg^{-1}.

Meteorological conditions in the 2018 (Fig. 1, 2)**.** In Viļāni, vegetation resumed in the second decade of April. Spring started rapidly in April, the average daily air temperature was 4.3 °C (and the total precipitation was 27.5 mm. The average air temperature in June was 15.6 °C, which is 0.8 °C higher than the norm, but the precipitation in June was 42.3 mm, which was 56.4% of the norm. The average air temperature in July was 19.2 °C, which is 2.3 °C higher than normal. The hottest time was in the 2nd and 3rd decades of July, but the amount of precipitation in July was 35.4 mm, In Viļāni, the average air temperature in August was 18.0 °C, which is 2.5 °C higher than normal. The hottest weather was in the 1st decade of August. Precipitation in August was 93.0 mm, which was 131.0 % of the norm. Precipitation in September was 29.4 mm, which was 47.4% of the norm. The dry weather was favourable for the harvest.

Meteorological conditions of the 2019 (Fig. 1, 2). In Viļāni, vegetation resumed in the first decade of April. From 9 to 16 April, when the daily average temperatures dropped below 5 °C, the active vegetation stopped and resumed on 17 April. The total amount of precipitation in Latvia in the spring was 100.5 mm, which is 18 % below the seasonal norm (122.7 mm). In Viļāni, the amount of precipitation in March was 31.1 mm, but in April there was no precipitation at all. On average in Latvia, the meteorological spring of 2019 lasted 98 days. June 2019, with an average air temperature of 18.6 °C became the warmest June in the history of observations. In August, the average air temperature was 17.0 °C. In Viļāni, the average air temperature in June was 18.9 °C July was cool, 1.6 ° C below normal, but August 0.3 °C warmer than normal.

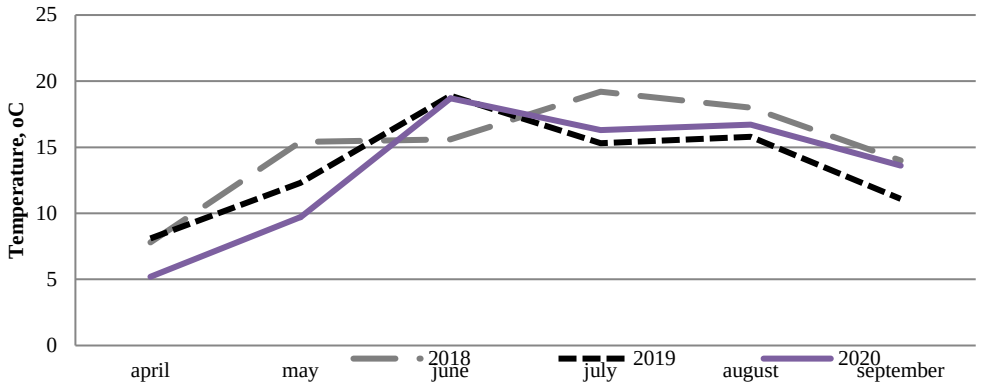

Figure 1 Temperature curves in all years of the study

Meteorogical conditions of the 2020 (Fig. 1, 2). In Viļāni, vegetation resumed in the first decade of April. The precipitation in April was lower than usually, but in may it was significantly higher than usually (84.7 mm), but in other vegetation period it was lower than usually. In April and may temperature a little lower than norm, in June it was significantly higher (18.7 °C) than norm, but in august and September temperature was little higher than norm.

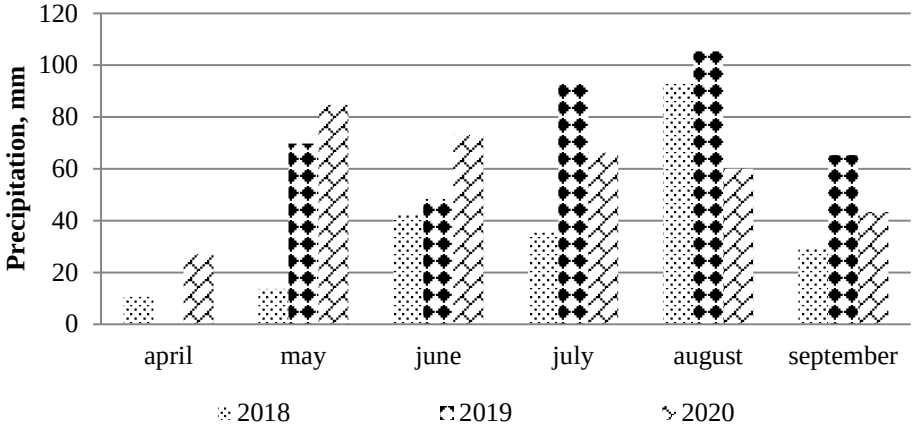

Figure 2 Precipitation in all years of the study

RESULTS

The most productive soybean cultivars was 'Merlin' in 2018 (3.68 t $ha^{-1}$and 2.80 t ha^{-1} accordingly) and 'Paradis' (1.68 t ha^{-1}). Pod formation, which is important for soybean productivity, took place in August and September. Significant impact on soybean seed yield in 2018 was for cultivar ($p < 0.001$) and sowing rate ($p < 0.001$), but the effect of row spacing was not significant in any of the experimental years. At a sowing rate of 60 germinating seeds per m^2, the yield was significantly higher in all trial years (Table 1). There was a tendency — the more plants per 1 m^2, the higher the yield.

There was no significant effect of row spacing, but still slightly higher seed-yield was available in variants with row spacing of 12.5 cm. In 2018, more productive was the cultivar 'Merlin' — 3.77 t ha^{-1}, but in 2019, the situation was different and the most productive cultivar was 'Paradis' 2.55 t ha^{-1}, in 2020, like in 2018, the most productive cultivar was 'Merlin' (Table 1).

TABLE 1 SOYBEAN YIELD IN 2018–2020 DEPENDING ON CULTIVAR, ROW SPACING AND SOWING RATE

Factors	**Soybean yield, t ha^{-1}**		
	2018	2019	2020
Cultivar			
p-value	< 0.001	< 0.001	< 0.001
'Lajma'	2.79	1.18	1.94
'Laulema'	2.03	1.93	2.44
'Merlin'	3.68	0.66	2.80
'Tiguan'	2.98	1.10	2.36
'Paradis'	2.76	1.59	2.48
'Touttis'	3.11	0.65	2.18
Row spacing, cm			
p-value	0.179	0.726	0.114
12.5	2.44	1.56	2.35
25	2.38	1.54	2.02
Sowing rate germinable seeds per 1 m^2			
p-value	< 0.001	< 0.002	< 0.001
40	2.22	1.52	1.74
50	2.29	1.49	2.17
60	2.72	1.65	2.66

Plant density (number of plants per 1 m^2) was determined when most soybean plants were at least 5 cm long — 15 AE (development phase). With the row space 12.5 cm — for the cultivar 'Lajma' the plant density was

from 27 plants per 1 m^2 at sowing rate 40 germinating seeds per 1 m^2 up to 36 plants per 1 m^2 at sowing rate 60 germinating seeds per 1 m^2. The plant density of the cultivar 'Laulema' was 26 plants 1 m^2 at sowing rate 40 germinating seeds per 1 m^2 up to 31 plants 1 m^2 at sowing rate 60 germinating seeds per 1 m^2 (see Table 2). With row spacing 25 cm — for the cultivar 'Lajma' the plant density was from 38 plants per 1 m^2 at the sowing rate of 40 germinating seeds per 1 m^2 to 47 plants per 1 m^2 at the sowing rate of 60 germinating seeds per 1 m^2. The results for both cultivars in all years shows that plant density was higher in the row space — 25 cm and when the highest sowing rates were used.

TABLE 2 NUMBER OF PLANSTS AND FIELD GERMINATION DEPENDING ON ROW SPACING ANDSOWING RATE IN 2018–2020

Cultivar	Row spacing, cm	Sowing rate germinable seeds per 1 m^2	Field germination, %	Number of plants per 1 m^2	Field germination, %	Number of plants per 1 m^2	Field germination, %	Number of plants per 1 m^2
Year			**2018**		**2019**		**2020**	
'Lajma'	12.5	40	66	27	97	39	70	28
		50	63	32	98	49	56	28
		60	59	36	92	55	47	38
	25	40	93	38	79	32	70	37
		50	89	45	73	37	56	39
		60	77	47	68	41	47	51
'Laulema'	12.5	40	65	26	95	38	70	38
		50	59	30	92	46	56	43
		60	51	31	95	57	47	53
	25	40	78	32	89	36	70	40
		50	86	43	83	42	56	51
		60	87	53	87	52	47	52

With row space 12.5 cm, the cultivars of the cultivar 'Lajma' had from 59% at the sowing rate of 60 germinating seeds per 1 m^2 to 66% at the sowing rate of 40 germinating seeds per 1 m^2 (Table 2). For the 'Laulema' cultivar, the yield is 51% at a sowing rate of 60 germinating seeds per m^2 to 65% at a sowing rate of 40 germinating seeds per 1 m^2. Overall, the yield was low. This could be due to the low moisture content of the soil during germination. For both cultivars, the field yield was higher at a larger row spacing — on average 83%.

Precipitation in May was 13.6 mm, which was 26.1% of the norm. Reduced soil moisture affected plant germination and development. Field germination in 2020 was similar in both row spacings for cultivar 'Lajma', there was no significant difference, but number of plants was higher with row spacing 25 cm. For the cultivar 'Laulema' row spacing did not affect the field germination and number for plants per 1 m^2 significantly. Compared to 2018, with row space 12.5 cm number of plants was higher was 30–40% higher. The field germination of the cultivar 'Laulema' was similar to that of 2018, but 10–15% lower for the cultivar 'Lajma', although the moisture supply during germination was sufficient — 69.8 mm in May.

TABLE 3 NUMBER OF PODS AND 1000 SEED WEIGHT OF SOYBEAN DEPENDING ON CULTIVAR, ROW SPACING AND SOWING RATE GERMINABLE SEEDS PER 1 m^2

Factors	Number of pods	1000 seed weight, g	Number of pods	1000 seed weight, g	Number of pods	1000 seed weight, g
Year	**2018**		**2019**		**2020**	
Cultivar						
p-value	< 0.001	< 0.001	0.007	0.081	0,0002	0.01
'Lajma'	37.5	175.13	23.8	159.44	42.5	165.68
'Laulema'	23.3	165.46	21.0	164.08	28.0	162.26
Row spacing, cm						
p-value	0.057	0.637	0.833	0.022	0.0001	0.001
12	29.1	169.79	22.5	158.68	45.00	160.45
25	31.7	170.79	22.2	164.85	37,67	166.58
Sowing rate germinable seeds per 1 m^2						
p-value	< 0.001	0.837	< 0.001	0.013	0,001	0.0002
40	33.8	170.94	25.6	161.14	32,3	159.87
50	30.9	170.50	21.3	167.01	33,5	162.36

60	26.5	169.44	20.3	161.76	44,3	161.25

Cultivar ($p = 0.007$) and sowing rate ($p < 0.001$) had a significant effect on the number of pods, but the effect on row spacing was not significant ($p = 0.833$). There were significantly more pods for the cultivar 'Lajma' — on average 23.8 pods for the plant, and for the cultivar 'Laulema' — on average 21.0 pods for the plant (Table 3). Among the sowing rate variants, significantly more pods were formed for plants at sowing rate 40 germinating seeds per 1 m^2 on average 25.6 pods, against sowing rate variants 50 and 60 germinating seeds per 1 m^2, which had on average 21.3 and 20.3 pods per plant, respectively. There were no significant differences between the row spacing variants — in the conventional row sowing variants only 0.3 pods per plant were formed on average than in the broad row sowing variants.

Spacing between rows ($p = 0.022$) and sowing rate ($p = 0.013$) had a significant effect on 1000 seed weight, but there was no significant effect on cultivar ($p = 0.081$). The coarser seeds were in the broad-row variants — on average 164.85 g, but in the conventional row-seed variants the weight of 1000 seeds were on average 158.68 g, or 6.17 g less. There was no significant difference between sowing variants 40 and 60 germinating seeds per 1 m^2 — on average 161.14 and 161.76 g, respectively, but for the sowing norm variant 50 germinating seeds per 1 m^2, the weight of 1000 seeds was 167.01 g. Compared to cultivars, the weight of 1000 seeds was higher for the cultivar 'Laulema' — on average 164.08 g, but for the cultivar 'Lajma' — 159.44 g (Table 3).

Cultivar ($p < 0.001$) and sowing rate ($p < 0.001$) had a significant effect on the number of pods, but the effect on row spacing was not significant ($p = 0.057$). As in 2018, there were significantly more pods for the cultivar 'Lajma' — on average 37.5 pods for the plant, and for the cultivar 'Laulema' — on average 23.3 pods for the plant (Table 3). Depending on the variant of the sowing rate, the same tendency was observed as in 2018 — there were more pods per plant in the variant of the lowest sowing norm — on average 33.8 pieces. In the sowing norm variant 50 germinating seeds per 1 m^2 there were on average 30.9 pods per plant, but in the sowing norm variant 60 germinating seeds per 1 m^2 — significantly less - on average 26.5 pods per plant. There were no significant differences in the number of pods for the plant between the usual row and broad-row variants - on average 29.1 pods for the plant in the conventional row-seed variants and on average 31.7 pods for the plant in the broad-row variants.

Cultivar had a significant effect on 1000 seed weight ($p < 0.001$), but row spacing ($p = 0.637$) and sowing rate had no significant effect ($p = 0.837$). The weight of 1000 seeds were significantly higher for the cultivar 'Lajma' — on average 175.13 g, compared to the average of 165.46 g for the cultivar 'Laulema'. In 2018, the weight of 1000 seeds were only 1.38 g less for the cultivar 'Laulema' and 15.69 g less for the cultivar 'Lajma'. The TSW (thousand grain weight) differed by only 1 g on average between the line spacing variants, which is not significant. There were also no significant differences between the variants of sowing norms. TSW averaged from 169.44 g at a sowing rate of 60 germinating seeds per 1 m^2 to an average of 170.94 g at a sowing rate of 40 germinating seeds per 1 m^2.

TABLE 4 SOYBEAN YIELD AND YIELD COMPONENTS DEPENDING ON YEAR'S METEOROLOGICAL CONDITIONS

Year	**Yield, t ha^{-1}**	**Number of pods**	**Number of pods on first productive knot**	**Number of seeds in firsts knot pods**	**1000 seed weight, g**
2018	2.41	22.3	3.65	1.49	161.76
2019	1.55	30.4	6.00	1.54	170.33
2020	2.20	30,68	3,3	1,01	162.56
p-value	0.012	0.006	< 0.001	0.237	< 0.001

The seed yield in 2018 was on average 2.41 t ha^{-1}, but in 2019 on average 1.55 t ha^{-1} — by 0.86 t ha^{-1} less, but in 2020 was 2.20 t ha^{-1}. The number of pods per plant was significantly higher in 2019 and 2020 — 30 pieces. against 22 pods per plant in 2018. The average number of pods at the first productive knot also increased in 2019 — 6.0 against 3.7 pods in 2018 and 3.3 pods in 2020. The mass of 1000 seeds were significantly higher in 2019 — on average 170.33 grams against 161.76 grams in 2018 and 162.56 grams in 2020 (Table 4). The highest values of the structural elements of the harvest could be explained by the fact that in the vegetation season of 2019 the plants had a more even moisture supply and there was no drought stress, which allowed to form more green masses — grow in length and form more productive branches, pods. But the first productive knot and pods formed lower, which made it difficult to harvest. However, the average yield in 2019 was significantly lower due to the large yield losses of the cultivar 'Lajma' at harvest, as the first node with pods was located only 3.8 cm from the soil surface. The only stable indicator over the years was the number of seeds in the pods of the first node - it differed between the years only by an average of 0.05 seeds.

DISCUSSION

Soybean is a short-day plant [5] Weather conditions at this time have a significant impact on soybean yield and harvesting potential. Consequently, in Latvia's conditions, pod formation, which is important for soybean productivity, takes place in August and September. Different meteorological conditions each year make it difficult to predict the ripening time of soybeans. When evaluating soybean cultivars, which are recommended as very early in other European countries, the results of the research in Latvia show that the vegetation time of the particular cultivars in Latvia's conditions does not always correspond to the early age group assigned by breeders [12]

In Brazil it has been found that a higher seed sowing rate (60 germinating seeds per 1 m^2) increase yield, especially in late sowing, as the total plant biomass per unit area, plant length, lower productive node height, number of pods and number of seeds per unit area increase. However, higher seeding rates reduce the shoot biomass, leaf area, number of pods and number of seeds per plant [10]

We concluded, however, that meteorological conditions during the growing season have a greater impact on the formation of the soybean yield than other factors. If it is cool and humid, the soybean vegetation period can be significantly extended, which hinders its ripening and makes harvesting more difficult (as it was in 2019 and 2020). Therefore, it is very important to choose earlier cultivars to avoid this risk.

Also, in Russia, it has been established that yield is significantly affected by the sowing rate [16] Study in USA indicate that soybean planted in narrow rows of 19 cm have higher yield potential when compared to soybean planted in wider rows [9]

The lower crop yield with 12 cm row spacing can be explained by the fact that the plants in the row have more competition for moisture and nutrients than in the conventional sowing[15]The same competitive tendency can be observed depending on the sowing norm — at the sowing norm of 60 germinating seeds per 1 m^2 the competition between germinating plants is higher than at the sowing norm of 40 germinating seeds per 1 m^2, which could affect field germination.

As Иванов, Мордвинцев (2014) demonstrate, increasing the sowing rate significantly reduced the number of pods per plant. At the sowing rate of 350,000 seeds per 1 ha per soybean plant there were on average 23.1 pods, but at the sowing rate of 550,000 seeds per 1 ha — 20.6 pods[14]Several authors (Грибанов, 2004; Иванов, Мордвинцев, 2014) have drawn the same conclusions about the productivity of soybean plants - there is an increase in plant productivity density (sowing rate), the lower the number of seeds in one pod, the number of pods, the mass of 1000 seeds, the number of productive branches. Some studies show that that soybean is more susceptible to water stress at the full seed beginning of pod, and beginning of seed reproductive stages and water stress also have impact on 1000 seed weight [3]

CONCLUSIONS

Experiments with soybean cultivars took place during significantly different vegetation seasons, which showed well the different reactions of cultivars to variations in meteorological conditions. Soybean seed yield was significantly influenced by cultivar choice, sowing rate and meteorological conditions of the year. It is important to choose cultivars with the shortest possible vegetation period so that the crop can be harvested until the autumn frosts. In 2018, more productive was the cultivar 'Merlin' — 3.77 t ha^{-1}, but in 2019, the situation was different and the most productive cultivar was 'Paradis' — 2.55 t ha^{-1}, in 2020, like in 2018, the most productive cultivar was 'Merlin' — 3.18 t ha^{-1}. The sowing rate of 60 germinable seeds per 1 m^2 ensured a significantly higher seed yield in both years. The quality of the yield varied from year to year as a result of meteorological conditions.

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