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Peculiarities of Physiological Development and Formation of the Harvest of the Narrow-Leaved Lupine under Various Weather Conditions

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ABSTRACT

Success in growing an agricultural crop is considered to be the maximum realisation of the potential of a variety, as well as a stable level of its yield over the years. In the article, the results of studies, conducted with the narrow-leaved lupine (*Lupinus angustifolius* L.) on the grey forest soil under the Forest-Steppe conditions were analysed. The peculiarities of the influence of hydrothermal conditions upon the duration of the period from sowing to the emergence of seedlings, interphase periods and the growing season, on the whole, were shown. An analysis of the influence of weather conditions over the years of the research and agrotechnical measures upon the generative development of the plants, the formation of the crop grain yield, as well as its quality upon the variant, recommended for production, in comparison with the control variant, was presented. The weather conditions that developed during the period from sowing to full ripeness of the narrow-leaved lupine plants differed significantly over the years of research, influenced the duration of the period from sowing to germination (from 7 to 15 days), the growing season of the crop, on the whole, (from 79 to 101 days), growth and development of plants, and – as a result– on the level of the yield. The seed yield in the experiment was unstable over the years even in the recommended production variant – from 3.28 to 2.10 t·ha^{-1}, that is, with a difference in the most favourable and unfavourable years of 1.18 t·ha^{-1}. The most favourable conditions for the formation of the crop were in 2016 on the variant, recommended for the production, and it provided for the application of $N_{68}P_{48}K_{66}$, sowing lupine of the "Pobeditel" variety with an inter-row spacing of 45 cm, a seeding rate of 1.2 million germinating seeds t·ha^{-1}, treated with a bioinoculant with a bioprotectant, and also foliar top dressing with microfertiliser at the IV stage of plant organogenesis. The year 2020 turned out to be the most unfavourable, as evidenced by the minimum yield level of 2.10 t·ha^{-1} and the index of the conditions of the year –0.51.

Keywords: lupine, generative development, quality, vegetation, crop yield.

INTRODUCTION

Due to the crop of lupine, it is possible to simultaneously solve the problems of protein and increase soil fertility. The narrow-leaved lupine (*Lupinus angustifolius* L.), in particular, is indispensable in organic farming because it has a relatively short growing season; it is a good precursor for many crops, helps maintain a positive balance of nutrients in the soil, loosens the arable and subarable horizons, and it has an ability to fix nitrogen from the atmosphere, it returns macro- and microelements to the root-containing layer, converting hard soluble compounds of phosphorus and potassium into accessible forms, leaving 80–220 kg of nitrogen, 30 kg of phosphorus and 50 kg of potassium for the subsequent crop rotation [Petrychenko, 2007; Takunova, 2001].

In recent decades, an increase in the acreage of fodder lupine has taken place mainly due to narrow-leaved lupine, yet its growth rates do not correspond to the importance of the crop for agriculture [Holodna, 2018]. One of the reasons for this situation is the unstable level of the lupine yield over the years, due to both agrotechnical measures and the variability of meteorological factors.

During the growing season, the plants of agricultural crops experience anthropogenic influence caused the growing technology, as well as the impact of external factors, which are particularly determined by the prevailing weather conditions. The factors are divided into the main ones, which are necessary for the plants, forming the conditions for the growth and development (light, heat, moisture and air), and the secondary ones which enhance or weaken the action of the main ones. Under today's conditions, the main factors in the plant life have the greatest influence [Alekseev, 2015; Alekseev, 2016]. The existing climate changes have led to the emergence of such problems in agricultural production as moisture deficiency and temperature stresses for plants. In the region of operation of the National Scientific Centre "Institute of Agriculture of the National Academy of Sciences", in particular, over the past 20 years, the excess of the average long-term values of the annual air temperature was 0.3–2.9°C. A rapid increase in heat in March was typical, as well as a significant excess of long-term average daily temperatures in July-August. There was also a deterioration in the level of the moisture supply due to insufficient rainfall. Regarding the nature of the seasonal distribution, their number approached or exceeded the average multi-year values in May, September and October, and there was a significant deficit in all the other months. Especially negative was the decrease in precipitation in July-August when many types of legumes undergo flowering and grain formation processes [Holodna & Lyubchych, 2021].

A feature of the narrow-leaved lupine plants is the taproot system that penetrates to a depth of 2.0 m, acting as a "biological" baking powder and is able to use moisture from deep soil layers, which makes them more resistant under the drought conditions, in contrast to the plants with a fibrous, superficially located root system [Larson et al., 1989; Proskura et al., 1979].

The generally accepted technologies for growing crops, in particular, the narrow-leaved lupine, do not fully take into account the natural adaptation of agrocenoses to the variability of weather conditions. Therefore, in order to reduce the influence of these factors upon the plants, a necessity arises to adapt the existing growing technologies to the constantly changing environmental conditions [Kaminsky et al., 2020]. Adaptation of the crop growing technologies will allow not only to better meet the needs of plants in the life factors but also to use resources more rationally, while obtaining stable crop yields and a high economic effect [Surgan, 2020].

The purpose of the research was to evaluate the influence of the cultivation methods and weather conditions upon the duration of the interphase periods of vegetation and the vegetation period of the narrow-leaved lupine plants, on the whole, their generative development, crop formation and quality.

MATERIALS AND METHODS

The research on the development of a technology for growing the narrow-leaved lupine was conducted on the experimental field of the Department of Legumes, Cereals and Oilseeds Technologies of the National Scientific Centre "Institute of Agriculture of the National Academy of Sciences ANAS" during 2016–2020.

The influence of agrotechnical practices and hydrothermal conditions during the years of research was assessed using the variant of cultivation technology, which involved the introduction of $N_{68}P_{48}K_{66}$ kg·ha^{-1} i.a. (the rate, calculated according to the genotypic ratio of elements in plants [Patent No. UA 133924, 2019]), sowing lupine of the Pobeditel variety in a wide row method (row spacing 45 cm) with a sowing rate of 1.2 million pcs/ha of germinated seeds, treated with the BTU-r bioinoculant in combination with the MycoHelp bioprotectant (1 l/t of seeds), and foliar top dressing with Tropikel microfertiliser (0.3 kg·ha^{-1}) at stage IV of the plant organogenesis, compared with the control variant, which did not include the use of mineral fertilisers and a bioprotectant for presowing seed treatment. This technology was eventually recommended for widespread introduction into production.

The meteorological conditions and their distribution during the growing season of the crop in the years of research differed significantly from each other and compared with long-term values; thus, it was possible to assess their impact upon the duration of the interphase periods of growth and development of the crop, as well as the growing season, as a whole, the generative development of the plants, the yield and quality of the produced grain. The variability and interrelation between these indicators and meteorological conditions were determined by using the method of correlation and regression analysis according to the method of B. Dospekhov [Dospekhov, 1985].

For the analysis, matrices of experimental data of multifactorial experience for each of the years of the study were used.

RESULTS AND DISCUSSION

Sowing of the narrow-leaved lupine was made in the first ten days of April, when the soil was physically ripe and warmed up to 5–8°C at the depth of seeding (Table 1).

The only exception was the year 2018, when such conditions occurred on April 17th, that is, in the second decade of the month. The sum of average daily air temperatures for the sowing period varied from 96.9 to 161.9°C, and the amount of precipitation varied from 0.6 to 20.8 mm. The calculated coefficients of variation show that the sum of the average daily temperatures during the sowing period had a strong degree of data dispersion (22.6%), while the amount of precipitation was characterised by their heterogeneity (105.9%) due to a significant degree of dispersion of the feature in the aggregate, which significantly affected the friendliness of seedlings and the period of their appearance.

It should be remarked that the largest amount of precipitation in March was recorded in 2018 – 61.5 mm at the norm of 39 mm. In the other years of research, the amount of precipitation was below the norm: in 2016 – 19.9 mm, in 2017 – 10.0 mm, in 2019 – 24.6 mm and in 2020 – 11.2 mm. The return of the cold weather, which was observed annually after sowing, did not contribute to the emergence of friendly seedlings either.

The shortest periods from sowing to germination were in 2016 and 2018 – 9 and 7 days, respectively, in other years they were longer – from 11 to 15 days. According to the graduation by M.K. Izhik, in 2016 and 2018 this period may be considered as medium, while in the other years it is long [Izhik, 1966]. According to the author, an increase in the period of germination affects the intensity of the seedling growth, because a significant part of the nutrient reserves is used by seeds for respiration and germination. The possibility that the seedlings may be damaged by diseases and pests also increases.

When analysing the variation of hydrothermal parameters, it should be remarked that the sum of the average daily temperatures during the sowing period in the years of research differed greatly, as evidenced by the coefficient of variation V = 22.6%, while for the entire growing season, it was insignificant (V = 8.9%). The humidification conditions differed significantly over the years of research, as evidenced by a significant degree of data dispersion (V = 44.0 and 105.4%). This influenced the vegetative and generative development of the narrow-leaved lupine plants and the level of indicators of the productivity elements.

Table 1. Hydrothermal indicators for the periods "sowing-sprouts" and "sprouts-full ripeness of the plants" of the narrow-leaved lupine during the years of research

Year	Date of sowing	Period "sowing-sprouts"		Period "sprouts-full ripeness"	
		Sum of average daily temperatures, °C	Amount of precipitations, mm	Sum of average daily temperatures, °C	Amount of precipitations, mm
2016	5.04	152.7	5.2	1541.1	162.3
2017	10.04	96.9	4.2	1431.8	52.6
2018	17.04	108.6	0.6	1556.6	142.3
2019	8.04	161.9	20.8	1685.4	112.6
2020	8.04	113.9	6.0	1801.0	215.4
V, %		22.6	105.9	8.9	44.0
On average for 2016–2020		126.8	7.4	1603.2	137.0

Mathematical models make it possible to calculate the duration of the period from sowing to germination, depending on the hydrothermal indicators (Table 2).

The dependence of the period duration on the sum of average daily temperatures was medium, as evidenced by the multiple correlation coefficient and the coefficient of determination (R = 0.713 and D = 50.8), and strong on precipitation (R = 0.912 and D = 83.2).

The duration of the vegetation period of agricultural crops is a genetic trait of the species, as well as the crop variety but, to a large extent, it depends on the growth conditions, determined, in particular, by the hydrothermal indicators [Pantsyreva, 2019]. In contrast to the "sowing seedlings" period, the duration of the interphase periods of the narrow-leaved lupine plants and the growing season, as a whole, largely depended on the amount of precipitation and the sum of average daily temperatures. During the years of research, the sum of average daily temperatures varied from 1431.8 to 1801.0°C (V = 8.9%), the amount of precipitation – from 52.6 to 215.4 mm (V = 44.0%), which, of course, had a different effect on the duration of the interphase periods and, as a result, on the duration of the growing season of the crop (Table 3).

It should be remarked that the growth and development of the narrow-leaved lupine plants in the variants within the experiment occurred simultaneously while a significant difference in the level of indicators was noted over the years of research. Therefore, in 2016, due to excessive precipitation and low average daily air temperatures the "branching-budding" interphase period was long and amounted to 28 days, which affected the growing season of the crop, extending it to 92 days. In 2018, with a deficit of precipitation, compared to the other years, the interphase period "seedlings-branching" was significantly shorter (8 days versus 12–16 days), which affected the growing season, as a whole, which lasted 79 days; and it was the shortest for the years of research. In 2020, due to excessive precipitation and a decrease in average daily air temperatures, the "branching-budding" interphase period lasted 32 days; however, the duration of other interphase periods was shorter than in other years; the interphase period "beginning of bean filling – full ripeness" lasted as long as possible (42 days); therefore, the duration of the growing season, as a whole, was 101 days, with an average of 89 days over the years of research.

When analysing the variation of the periods by years (Fig. 1), it was found that the indicators of the duration of the period from sowing to germination differed significantly (V = 28.1%).

It should be noted that the difference between the indicators of the duration of the period from sowing to full ripeness was insignificant (V = 6.5%), while in the period "sprouting-branching"

Table 2. Mathematical models of the duration of the period "sowing seedlings" depending on the hydrothermal indicators, on average for 2016–2020

Equation	Multiple correlation coefficient, R	Determination coefficient, D
$T = 317.1751 + 2.4775X – 55.3860X^{0.5}$	0.713	50.8
$T = 5.1881 – 0.1173X_1 + 2.6725X_1^{0.5}$	0.912	83.2

Note: T – duration of the period, days; X – the sum of the average daily temperatures, °C; X_1 – the rainfall, mm.

Table 3. Duration of the "sowing seedlings" period and interphase periods of development of the narrow-leaved lupine plants by years of research, days

Period	Year of research					V,%	Average for 2016–2020
	2016	2017	2018	2019	2020		
Sowing seedlings	9	12	7	15	11	28.1	12
Seedlings – branching	13	16	12	13	14	11.2	14
Branching – budding	28	20	16	10	32	42.0	21
Budding – flowering	6	6	9	12	6	34.4	7
Flowering – pod formation	6	5	5	7	4	21.1	5
Formation of beans – start filling of beans	8	7	5	3	3	43.9	5
Start filling of beans – full ripeness	31	33	32	41	42	14.7	35
Seedlings – full ripeness	92	87	79	86	101	6.5	89

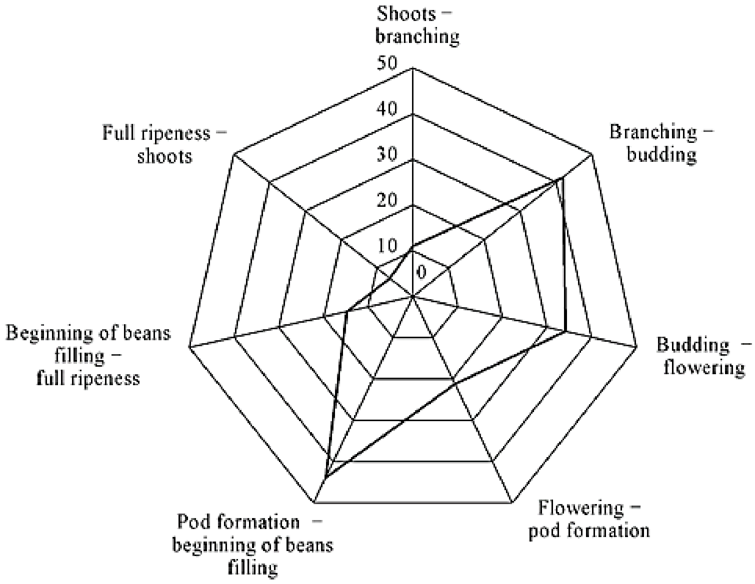

Fig. 1. Variation in the duration of the interphase periods over the years of research, %

and "bean filling-full ripeness" it was medium (V = 11.2 and 14.7%), the remaining indicators of the duration of interphase periods being strong (V = 21.1 and 43.9%).

Various hydrothermal conditions that developed during the years of research, as well as the studied agrotechnical methods, influenced the generative development of the narrow-leaved lupine plants and the level of indicators of the productivity elements (Table 4).

In the variant, recommended for production, based on the results of five-year studies, the maximum number of flowers – 56.3 and 56.8 pcs·(plant)$^{-1}$, and formed pods – 26.2 and 24.7 pcs·(plant)$^{-1}$ (which amounted to 44.6 and 43.5% of the number of flowers), were observed, in the years 2016 and 2019, respectively. Despite the fact that the weight of 1000 grains was only 104 and 99 g, the determining elements of the structure in the formation of the yield level were the number of beans that remained until the full ripeness of the plants, and, accordingly, the number of grains in the plants.

During the growing season of the narrow-leaved lupine in the years 2017 and 2018, which can be characterised as dry, only 16.6 and 23.6 flowers per plant were observed; however, a significantly larger number of beans were set from them in the percentage terms, compared to 2016 and 2019 – 60.8 and 59.7%. Until the phase of full ripeness, only 7.8 and 10.9 beans remained on the lupine plants, respectively. However, the weather conditions contributed to the active filling of seeds, which ensured a maximum level of the weight indicators for 1000 grains – 117 and 123 g. In these years, this element of the yield structure was decisive in the formation of the crop yield level.

Excessive precipitation and a decrease in the average daily air temperatures during the "branching-budding" interphase period in 2020 did not contribute to the generative development of the lupine plants and preservation of the beans to full ripeness (which was a limiting factor in the formation of the crop yield). Despite the severe drought in the subsequent periods of development, large seeds were formed – the weight of 1000 grains was 121 g, which finally determined the level of the crop.

In the control variant of the experiment, the agrotechnical methods which differed from the variant, recommended for production, in the absence of mineral fertilizers and a bioprotectant for presowing seed treatment, the number of flowers, on average, was formed by 40.8% less over the years of research, the number of beans, less by 7.0%, was formed; 33.6% less beans remained until the full ripeness phase.

It should be noted that the percentage of set pods in relation to the formed flowers in the control variant in all the years of research was significantly higher than in the recommended production variant, although in numerical terms, respectively, they were set on average by 1.2 pcs/plant less. During the growing season, the best preservation of the pods was observed in the recommended production variant, where, before the phase of full ripeness over the years of research, on average, 13.1 pods remained on the plant, or 72.2% of the number of the set ones, while in the control variant the figures were 8.7 pcs·(plant)$^{-1}$, or 55.5%, respectively.

The most favourable conditions for the formation of the crop in the variant, recommended for production, were formed in 2016, as evidenced by the maximum level of the narrow-leaved lupine grain yield in the experiment – 3.28 t·ha^{-1} and the index of the conditions of the year +0.69, less favourable in 2018 – 2.80 t·ha^{-1} and the year conditions index +0.19; 2019 –2.57 t·ha^{-1} and –0.04; 2017 – 2.29 t·ha^{-1} and –0.32. The year 2020 turned out to be the most unfavourable, as indicated by the minimum yield level of 2.10 t·ha^{-1} and the index of the conditions of the year –0.51.

The rate of crude protein harvest clearly depended on the level of the crop and the content of the crude protein in the grain.

On average, over the years of research the yield of the lupine grain in the recommended production variant exceeded the level of the control variant (1.95 t·ha^{-1}) by 0.66 t·ha^{-1}, or 33.8%, which indicates the high efficiency of the introduced agricultural practices.

The dependence of the narrow-leaved lupine grain yield on the hydrothermal conditions is described by the correlation equations presented in Table 5.

The coefficients of variation of 55.6 and 58.3% testify to the significant variability of the indicator of the number of flowers over the years of research in both variants. The variability of the indicators of the number of plants that started and remained until the full ripeness phase was also strong: the coefficients of variation were 45.1 and 46.0%, 48.8 and 47.6%, respectively. The variability of the yield index was medium (V = 16.3 and 17.7%), the yield of crude protein was also (V = 16.0 and 19.1%), while the weight of 1000 grains and the content of crude protein in the grain were weak, as evidenced by the corresponding coefficients of variation.

Table 4. Formation of the yield and grain quality of the narrow-leaved lupine during the years of research by various models of the growing technology

Indicator		Year of research					V, %	Average for 2016–2020
		2016	2017	2018	2019	2020		
Control variant								
Formation of flowers, pcs·(plant)$^{-1}$		38.7	11.4	15.4	26.4	12.5	55.6	20.5
Starting of beans	pcs·(plant)$^{-1}$	24.1	9.8	12.9	23.2	9.6	45.1	15.9
	% of flowers	65.7	86.0	83.8	87.9	76.8	–	–
Preserved beans	pcs·(plant)$^{-1}$	13.0	5.0	4.5	13.3	7.7	48.8	8.7
	% of the started beans	53.9	51.0	34.9	57.3	80.2	–	–
Mass (weight) of 1000 grains, g		109	109	102	100	123	8.5	109
Crop yield, t·ha^{-1}		2.47	1.73	1.83	2.04	1.70	16.3	1.95
Index of conditions of the year, j		+0.52	–0.22	–0.12	+0.09	–0.25		
Crude protein	content in a grain, %	33.2	33.5	33.8	32.4	32.8	1.7	33.1
	collection, t·ha^{-1}	0.82	0.58	0.62	0.66	0.56	16.0	0.65
Recommended option for production								
Flowers formed, pcs·(plant)$^{-1}$		56.3	16.6	23.6	56.8	19.8	58.3	34.6
Beans started	pcs·(plant)$^{-1}$	26.2	10.1	14.1	24.7	10.2	46.0	17.1
	% of the flowers	44.6	60.8	59.7	43.5	51.5	–	–
Preserved beans	pcs·(plant)$^{-1}$	20.0	7.8	10.9	19.3	7.3	47.6	13.1
	% of the started beans	76.3	77.2	77.3	78.1	52.0	–	–
Mass (weight) of 1000 grains, g		104	117	123	99	121	9,5	113
Crop yield, t·ha^{-1}		3.28	2.29	2.80	2.57	2.10	17.7	2.61
Index of conditions of the year, I_j		+0.67	–0.32	+0.19	–0.04	–0.51	–	–
Crude protein	content in a grain, %	33.4	33.3	34.3	32.8	32.4	2.2	33.2
	collection, t·ha^{-1}	1.10	0.76	0.96	0.84	0.68	19.1	0.87

Table 5. Mathematical models of dependence of the yield of the narrow-leaved lupine grain on the hydrothermal indicators of the period "seedlings-full ripeness", on average, for 2016–2020

Equation	Multiple correlation coefficient, R	Determination coefficient, D
$Y = -129.3451 - 0.0821X + 6.5720X^{0.5}$	0.667	44.5
$Y = -1.1879 - 0.0262X_1 + 0.5883X_1^{0.5}$	0.593	35.2

Note: Y – crop yield $t \cdot ha^{-1}$; X – sum of average daily temperatures, °C; X_1 – amount of precipitation, mm

The climatic changes, observed in recent decades, are characterised by deviations from the average long-term indicators of precipitation and average daily air temperature, and variability of weather conditions within the years. Increasingly frequent manifestations of extreme weather phenomena are felt during the critical periods of the plant ontogenesis, causing stressful condition in them, changing the intensity and direction of the physiological processes, which determine the formation of the final yield of crops [Pachauri & Reisinger, 2008; Field et al., 2012; Pyatigyn, 2021]. The recommended technologies for growing the narrow-leaved lupine do not fully take into account the possibilities to adapt the agrophytocenoses of the crop to the variability of the weather conditions, its biological characteristics. The technology of growing the narrow-leaved lupine requires rethinking in order to adapt it to constantly changing environmental factors throughout the growing season, from the seed germination to the full grain ripeness [Georgieva & Kosev, 2018; Kosev et al., 2019; Kosev & Vasileva, 2019; Kosev & Vasileva, 2020]. The research of the narrow-leaved lupine should be aimed at reviewing the elements of the cultivation technology in order to adapt to the conditions of the climate change, which will reduce the level of the harm, caused by such phenomena, making the most efficient use of the existing resources and developing appropriate response strategies.

CONCLUSIONS

The results of the studies, presented in the article, and their analysis indicate that under the conditions of the climate change, observed in recent decades, the growth and development of plants, the level of the grain yield of the narrow-leaved lupine of variety "Pobeditel" and its quality differed over the years of research and, to a large extent, it depended on the weather conditions that developed during the growing season of the crop. In the variant, recommended for production according to the research results, the index of the conditions of the year varied from +0.67 to –0.51. The stress factors were both the amount of precipitation during the growing season of the crop, as evidenced by the correlation coefficient (R = 0.593), and the fluctuations in the sum of average daily air temperatures (R = 0.667). The crop yield was unstable over the years – from 3.28 to 2.10 $t \cdot ha^{-1}$, that is, with a difference in the most favourable and unfavourable years of 1.18 $t \cdot ha^{-1}$. The weather conditions also influenced the quality of the products obtained – the content of crude protein in the grain ranged from 32.4 to 34.3%, and its collection depended on the level of the crop yield. To reduce the influence of unregulated factors and obtain a stable grain yield over the years, it is necessary to create the varieties that are resistant to adverse conditions, as well as to use biological preparations, anti-stress agents, the plant growth stimulants, as well as mineral fertilisers in the required norm during critical growth periods for the plants and their development.

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