Plant and Soil Science

Journal homepage: https://agriculturalscience.com.ua/en
Plant and Soil Science, 13(3), 49-59
Received: 21.02.2022 Revised: 29.06.2022 Accepted: 01.08.2022

UDC 633.31:58.055

DOI: 10.31548/agr.13(3).2022.49-59

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Influence of hydrothermal factors on feed and seed productivity of alfalfa in the conditions of the Right-Bank Forest-Steppe

Abstract. The relevance of the study is due to the need to examine the influence of hydrothermal resources of the region on the formation of the crop of leaf-stem mass and alfalfa seeds, which is important in the conditions of modern climate changes. In this regard, the purpose of the study is to identify the influence of precipitation and temperature conditions on the growth and development of plants of varieties and hybrids by harvest cycles and years of use of the herbage. In the course of the study, the following methods were used: field (conducting phenological observations and accounting), laboratory (structural analysis of the grass stand), mathematical-statistical (objective assessment of the obtained experimental data). It was identified that the amount of precipitation from the beginning of the period of the relative rest to the onset of active temperatures above 10°C had the greatest impact on the formation of the 1st harvest; the amount of precipitation after the establishment of active temperatures above 10°C and before accounting for the yield of leaf-stem mass moderately affected the formation of the 2nd harvest and strongly – the 3rd; the amount of precipitation of the previous harvest – the 2nd-4th harvest (the strongest – the 4th); the sum of active temperatures above 10°C – the 1st and 3rd harvests; indicators of hydrothermal coefficient – the 2nd-3rd; duration of the growing season with active temperatures above 10°C – the 1st and 3rd harvests. Seed yield, in contrast to feed productivity, largely depended on the amount of precipitation before the flowering phase and in general during the growing season of alfalfa. It is established that the yield of dry matter and seed yield are influenced by: the sum of active temperatures, the amount of precipitation per harvest or vegetation of plants, and the genetic characteristics of the hybrids and varieties under study. It was identified that the hydrothermal conditions of the year have different effects on the level of plant productivity – excessive and sufficient moisture increases feed productivity and reduces seed yield. The data obtained are of practical value for predicting the yield of green mass of alfalfa each subsequent harvest of the herbage, depending on the amount of precipitation during the growing season of the previous one, and for developing programmes for creating synthetic varieties with increased yield of leaf-stem mass and seeds

Keywords: hybrid, hydrothermal coefficient, harvest cycle, dry matter yield, seed yield, correlation

INTRODUCTION

Alfalfa is one of the most productive and widespread forage crops in the world. The value is not limited only to its feed benefits, it is also important in the biologisation of Agriculture. Alfalfa (*Madisago sativa* L.) is one of the oldest agricultural plants in the world, which, in pure crops and as part of grass mixtures, provides a high yield of green mass with a high content of digestible protein and in the process of symbiotic nitrogen fixation enriches the soil with biological nitrogen, which in the conditions of an energy crisis is important for increasing soil fertility (Bugayov & Zadorozhnay, 2012).

There is an increase in the interest of researchers in the use of this culture in medicine and the food industry, which indicates its versatility and the prospect of further research (Apostol *et al.*, 2017; Rafinska *et al.*, 2017; Yakhlef *et al.* 2020). Due to its plasticity in terms of

Suggested Citation:
Petrychenko, V.F., Korniichuk, O.V., Buhaiov, V.D., Horenskyi, V.M., & Veklenko, Yu.A. (2022). Influence of hydrothermal factors on feed and seed productivity of alfalfa in the conditions of the Right-Bank Forest-Steppe. *Plant and Soil Science, 13(3), 49-59.*

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longevity and resistance, alfalfa is the most suitable crop for biotic and abiotic factors. However, according to its biological characteristics, alfalfa plants grow well and develop at a pH of 6.5-7.5. A decrease in the reaction of the soil solution to pH 5.1-5.5 negatively affects the enzymatic apparatus of cells, which leads to inhibition and suspension of synthesis processes in plants, disruption of hydrocarbon and protein metabolism. Alfalfa is one of the crops that responds best to soil liming (Hetman *et al*., 2017). According to the agrochemical certification of arable land in Ukraine, the area of acidified soils is 3.7-4.4 million hectares. In particular, in the zone of Forest-Steppe and Polesia, such soils occupy 25-37%. Alfalfa crop losses on acidic soils reach 20-40% (Baliuk *et al*., 2010; Melnyk, 2010). This is especially true for seed formation under such conditions (Buhaiov & Horenskyi, 2021). Therefore, increasing seed productivity will continue to be one of the main areas of breeding this crop.

It is known that most studies on alfalfa breeding are aimed at creating varieties adapted to abiotic and biotic factors of the growing area (Tyshchenko & Tyshchenko, 2014), improving or developing certain agrotechnical techniques aimed at increasing feed and seed productivity (fertilisation, sowing dates and norms, plant protection, etc.) (Hetman *et al*., 2017; Noskova, 2015). However, researchers do not always consider the hydrothermal resources of the research site. It is established that the amount of precipitation and the sum of active temperatures of a particular year substantially differ from the average annual values, especially recently, in the conditions of climate change, and this accordingly affects the productivity of the crop (Petrychenko *et al*., 2020).

Alfalfa (*Medicago sativa* L.) among other perennial legumes, is the most common forage crop in all soil and climatic zones of Ukraine. It provides the production of high-quality protein feed and promotes the biological reproduction of soil fertility (Petrychenko *et al*., 2018). A substantial amount of studies has been conducted to improve the agricultural technology of alfalfa cultivation for feed and seed purposes under various agroclimatic conditions in Ukraine. Optimal terms and methods of sowing, seeding rates, and application of mineral fertilisers were identified (Demydas *et al*., 2010; Petrychenko *et al*., 2020). Considerable attention is paid to the development of ways to increase the proportion of symbiotic nitrogen fixed by alfalfa plants in symbiosis with nodule bacteria (Holoborodko, 2021; Tyshchenko *et al*., 2018). A positive effect of growth stimulators and microfertilisers on the formation of leaf-stem mass and seeds of alfalfa varieties was identified (Vlasenko *et al*., 2003; Vozhehova *et al*., 2021; Tyshchenko *et al*., 2020). A number of researchers have considered the ecological and genetic foundations of adaptive crop production (Zaporizhchenko *et al*., 2018; Ivashchenko & Rudyk-Ivashchenko, 2011; Karta, 2006). Creating favourable conditions for the growth and development of alfalfa plants involves a scientifically based approach to adapting them to natural and climatic conditions, considering genetic, biological, and hydrothermal factors (Hetman *et al*., 2017; Noskova, 2015; Lili *et al*., 2019). Despite the substantial success of Ukrainian breeding, it is relevant to create alfalfa varieties with a combination of high seed and feed productivity and adaptability (Buhainov & Gorenskyi, 2021; Tyshchenko & Tyshchenko, 2014). A number of researchers have identified that aluminium ions at the physiological, biochemical, and molecular levels have both stimulating and toxic effects on the growth of alfalfa plants (Buhaiov *et al*., 2014; Khu *et al*., 2012).

The formation of seed productivity is influenced by a number of factors: increased soil acidity, insufficient supply of nutrients, lack of a sufficient number of pollinating insects, hydrothermal conditions, abortivity of flowers and beans (Rudska, 2016; Bolaños-Aguilara *et al*., 2002; Katepa-Mupondwa *et al*., 1996).

The purpose of the study – identification of the influence of hydrothermal conditions of the year on the processes of growth, development, and formation of the yield of leaf-stem mass of alfalfa, depending on the harvest and years of use.

MATERIALS AND METHODS

The study was conducted in 2013-2020 at the Institute of Feed Research and Agriculture of Podillya of the National Academy of Agrarian Sciences of Ukraine, located in the Right-Bank Forest-Steppe of Ukraine, Vinnytsia district, Vinnytsia region. Vinnytsia district is located in the central zone of the Vinnytsia region, which is characterised by a moderately warm and humid climate typical of the Central Forest-Steppe. The hydrothermal coefficient (HTC) is 1.7-1.8. Precipitation during the year is 534-540 mm. Of this amount, about 70% is during the warm period of the year. The soil cover of the fields where the studies were conducted is represented by grey forest medium-loamy soils with a pH of salt extract from 5.0 to 5.5 and a hydrolytic acidity of 26-28 mg.-eq/1 kg of soil. Humus content is 1.5-1.8%; easily hydrolysed nitrogen – 34-54 mg.-eq/1 kg of soil; mobile phosphorus 100-120, and exchange potassium 120-140 mg.-eq/1 kg of soil. The degree of soil saturation with bases is 85.7%. Samples of alfalfa (Syniukha (UJ0700134), Regina (UJ0700031), Yaroslavna (UJ0700225) (Ukraine); Vika (Denmark); Mega (UJ0700365), Grilys (Uj0700772) (Sweden), Zhidrune (UJ0700699, Lithuania), and 37 hybrid populations, created with their involvement, were used as research materials of the third and fifth generation. Its predecessor is winter triticale. Mineral fertilisers were applied for sowing in a dose of $N_{30}P_{60}K_{30}$ kg/ha. In autumn, every year the herbage of the second and subsequent years of use was supplemented at a dose of $P_{60}K_{30}$ kg/ha. Seed herbage was additionally supplemented annually with foliar boric and molybdenum preparations, and if necessary, insecticide treatment was conducted in the budding and seed formation phase.

Laying of breeding nurseries was conducted by the summer coverless method of sowing (10-15 June): continuously (15 cm) – to assess feed productivity, and wide-row (45 cm) – seed with the corresponding seeding rate of 8 and 3.5 million tonnes germinating seeds/1 ha. The area of the registered plot is 3 m² in the F_3 nursery and 10 m² – in F_5. Sowing with a Maple 1.5 selection seeder, the depth of seed embedding is 1.5-2 cm. Evaluation of the yield of green mass and seeds was conducted on alfalfa stands of the first, second, third, and fourth years of use. Field studies and phenological observations were conducted in accordance with methodological recommendations (Andriushchenko *et al*., 2010). The data from four harvests were used at the onset of the budding phase to account for feed productivity – the beginning of flowering, seed – from the grass stand of the first harvest. In the future, the average dry matter yield along the harvests was used for calculations. Accounting of the seed harvest was conducted by a Sampo 130 small-sized harvester.

For a brief description of hydrothermal conditions, the period 2013-2020 is given, which is characterised by a heterogeneous distribution of precipitation and temperature regime in comparison with the perennial average values (Table 1).

Table 1. Hydrothermal parameters

Parameter	2013	2014	2015	2016	2017	2018	2019	2020	Perennial average
Average air temperature, °C	16.0	17.6	18.8	17.0	17.9	17.7	16.7	18.1	16.5
Sum of precipitation, mm	418.5	385.8	160.7	213.9	266.0	370.3	364.4	302.0	409.0
Sum of active temperatures >10°C ,	2937.9	2164.8	2877.7	3114.9	2743.2	3250.4	2562.6	2767.3	2521.0
HTC[1]	1.42	1.78	0.56	0.69	0.97	1.14	1.42	1.09	1.62

Notes: [1]HTC (hydrothermal coefficient)

The Selyaninov hydrothermal coefficient was calculated (Polovyi *et al*., 2012), according to which 2015 corresponds to the conditions of severe drought, 2016, 2017 – mild drought, 2013, 2018, 2019, 2020 – sufficiently humid conditions, and 2014 – excessive moisture to improve the perception of such conditions. In general, in comparison with the perennial average values, a substantial decrease in precipitation and an increase in the sum of active temperatures is observed, which had an ambiguous effect on the level of feed and seed productivity.

Statistical processing of data was performed using Agrostat, IBM SPSS Statistics, and Microsoft Excel software.

RESULTS AND DISCUSSION

During the research period of 2013-2020, it was identified that hydrothermal factors were characterised by a heterogeneous distribution of precipitation and temperatures. An analysis of the level of dry matter yield along the harvests was conducted to objectively assess their impact.

Thus, from the time of relative dormancy of plants to the establishment of average daily temperatures of above 10°C (approximately from November to the beginning of April ±10-15 days), the amount of precipitation ranged from 177 mm in 2013 to 313 mm in 2017, or on average for years of research – about 230 mm. The amount of precipitation received after the onset of average daily temperatures of above 10°C and before the time of the first harvest also varied substantially over the years and ranged from 15 mm (2018) to 136 mm (2019). It is noted that the sum of active temperatures above 10°C varied greatly (Table 2).

Table 2. Dry matter yield in hybrid alfalfa populations (F_3 and F_5) and hydrothermal indicators of 2013-2020 (1st and 2nd harvests)

Years	1st harvest					2nd harvest			
	Total precipitation (rest state – onset of t_{fact}>10°C), mm	Precipitation amount (t_{fact}>10°C – accounting), mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m	Sum of precipitation, mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m
2013	176.9	60	859.2	0.70	4.81±1.12	107	722	1.48	2.51±0.41
2014	193.2	57	392.5	1.45	3.13±1.25	152	759.4	2.0	2.93±1.06
2015	224	39	406.1	0.96	3.20±1.1	28.3	629.5	0.45	1.81±0.86

Table 2, Continued

Years	1st harvest					2nd harvest			
	Total precipitation (rest state – onset of t_{fact}>10°C), mm	Precipitation amount (t_{fact}>10°C – accounting), mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m	Sum of precipitation, mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m
2016	237	68	559.4	1.22	3.21±1.46	63	681.7	0.92	2.99±1.32
2017	313	51	558.6	0.91	7.00±0.87	24	656.1	0.37	2.40±0.42
2018	258	15	562.4	0.27	4.77±0.6	100.5	785.8	1.28	2.67±0.39
2019	231.4	136	407	3.34	4.59±0.56	74	639.6	1.16	3.29±0.48
2020	201	79.5	312	2.54	3.8±0.44	127.5	688	1.85	2.99±0.48
Average	229.31	63.19	507.1	1.42	4.31±1.44	84.54	695.26	1.19	2.70±0.46

In terms of the yield of dry matter in the first harvest, 2017 should be highlighted – 7 t/ha. Evidently, this is due to substantial precipitation during the period of relative dormancy of plants, which allowed forming sufficiently high reserves of productive moisture in the soil, and, despite a weak drought in the spring (HTC – 0.91), plants were able to fully realise their genetically determined yield level. Therewith, the dry matter yield in other years was in the range of 3.13-4.81 t/ha. It is necessary to highlight 2013, when this indicator was 4.8 t/ha, 2018 – 4.77, and 2019 – 4.57 t/ha with HTC of 0.7, 0.27, and 3.34, respectively.

In 2013 and 2019, a fairly high level of precipitation in winter also substantially affected the formation of the leaf-stem mass. In 2018, the dry matter yield was most strongly affected by precipitation during the relative rest period, since after setting active temperatures of above 10°C , rather harsh conditions developed (HTC – 0.27, precipitation – 15 mm). Alfalfa plants needed from 26 to 53 days with active temperatures of above 10°C to form a crop in the first harvest. In the second harvest, precipitation also varied substantially over the years – from 152 mm in 2014 to 24 mm in 2017. Thus, according to the HTC indicator (0.37), 2017 corresponded to the conditions of a very strong drought, 2015 (0.45) – a strong drought, 2016 (0.92) – a weak drought, 2013 (1.48), 2018 (1.28), 2019 (1.16) – sufficiently humid conditions, and 2014 (2.0) and 2020 (1.85) – excessive moisture.

The dry matter yield was in the range of 1.81-3.29 t/ha. Therewith, an increase in the value of this feature was observed depending on the increase in precipitation. The sum of active temperatures increased and ranged from 629.5 to 785.8°C , and the number of days before harvest, on the contrary, decreased to 31-43. Hydrothermal conditions can be considered more unfavourable for the formation of yield on harvests 3 and 4 (Table 3).

Table 3. Dry matter yield in hybrid alfalfa populations (F_3 and F_5) and hydrothermal indicators of 2013-2021 (3rd and 4th harvests)

Years	3rd harvest				4th harvest			
	Sum of precipitation, mm	Sum of active temperatures (t fact>10), °C	HTC	Dry matter collection, t/ha M±m	Amount of precipitation (before accounting), mm	Sum of active temperatures (t fact>10), °C	HTC	Dry matter yield, t/ha M±m
2013	46.2	827.4	0.56	2.79±0.7	174.7	739.5	2.36	0.94±0.2
2014	54	756.9	0.71	1.90±0.75	102	905	1.13	0.89±0.25
2015	22	801.8	0.27	1.49±0.69	41	1313	0.31	1.21±0.55
2016	44	602	0.73	1.89±0.83	35	974.4	0.36	1.09±0.48
2017	61	736	0.83	1.64±0.34	64	760.3	0.84	0.51±0.11
2018	187	791.3	2.36	3.31±0.38	58.8	887.4	0.66	2.37±0.3
2019	68	783	0.87	2.00±0.40	9.3	836.9	0.11	0.60±0.17
2020	49	721	0.68	1.60±0.35	36.4	953.5	0.38	1.00±0.17
Average	66.4	752.43	0.88	2.08±0.65	65.15	921.25	0.77	1.08±0.57

Thus, the amount of precipitation before the 3rd harvest was in the range of 22-68 mm (with the exception of 2018 – 187 mm), on the 4th – 9.3-64 mm (with the exception of 2013 – 174.7 and 2014 – 102 mm). The sum of active temperatures, in comparison with the first and second harvests, increased and amounted to 752.4°C in the 3rd harvest and 921.2°C in the 4th, and the number of days for crop formation was 28-42 in the 3rd and 42-74 days in the 4th. The HTC values, respectively, except for some exceptions, were less than 1 and linked to various drought variants, which had a corresponding effect on the level of dry matter yield, which in the 3rd harvest was 1.49-3.31 t/ha and in the 4th – 0.51-2.37 t/ha. In total, for four harvests, the yield of dry matter of alfalfa in hybrid nurseries was: 2013 – 11.05 t/ha; 2014 – 8.85; 2015 – 7.71; 2016 – 9.18; 2017 – 11.55; 2018 – 13.12; 2019 – 10.48; 2020 – 9.39 t/ha, or on average – 10.17 t/ha.

For a more complete perception of the dependence of the level of feed productivity on hydrothermal factors and the duration of the growing season, correlation coefficients between these features are calculated (Table 4).

Table 4. Dependence of dry matter yield on harvests on hydrothermal factors and the duration of the growing season

Harvest	Amount of precipitation, mm (autumn-winter before the onset of active temperatures of above 10°C, potential moisture reserves)	Amount of precipitation, mm (after the onset of active temperatures above 10°C before accounting)	Amount of precipitation, mm (previous harvest)	Sum of active temperatures above 10°C	HTC	Number of days before harvest with (t fact>10), °C
1	0.69[1]	-0.05	–	0.39[1]	-0.17	0.63[1]
2	-0.16	0.52[1]	0.66[1]	0.20	0.58[1]	0.17
3	-0.09	0.78[1]	0.33[1]	0.39[1]	0.75[1]	0.46[1]
4	–	-0.06	0.78[1]	0.24	-0.10	0.03

Notes: [1] – the correlation is substantial at 0.05

According to the obtained calculations, the manifestation of dependencies was identified, characterised by a strong relationship between the amount of precipitation from the beginning of the relative rest period and the sum of active temperatures above 10°C – 0.69. It is noted that winter precipitation did not affect the subsequent harvests. Therewith, the amount of precipitation after the establishment of active temperatures above 10°C and before harvest ripeness moderately affected the formation of the 2nd harvest (0.52) and strongly – the 3rd (0.78), while no effect was identified on the 4th. This is due to the fact that with a decrease in the length of daylight at a relatively high average daily temperature, the duration of the inter-harvest period and the average daily linear growth icrease (Hetman *et al.*, 2018; Lili *et al.*, 2019).

Notably, the productivity of alfalfa plants largely depends on the intensity of shoot formation, which is influenced by various factors, in particular, soil and meteorological conditions (Georgieva & Nikolova, 2015). The regrowth of alfalfa after harvesting in different harvests has its own characteristic features. It is known that in the first harvest, shoots are formed from the crown of the root of plants, and in the second, third and fourth – 54-78% of shoots are formed due to the axillary buds of the plant stem and only 22.1-46.2% – from the buds of the root crown. Stems formed from the buds of the root crown are characterised by a larger mass compared to shoots formed from the stem axillary buds (Hetman *et al.*, 2018; Petrychenko *et al.*, 2021;).

Thus, the feed productivity of alfalfa is affected not only by precipitation during the growing season of plants of a particular harvest but also by the previous one, since plants lay buds to restore shoots throughout almost the entire growing season. The identified dependencies were confirmed by the corresponding correlation coefficients: in the 2nd harvest – 0.66, in the 3rd – 0.33, and, especially, in the 4th – 0.78. The sum of active temperatures above 10°C was characterised by an average effect on the level of feed productivity in the 1st and 3rd harvests.

According to the level of the HTC indicator, the average correlation coefficient was identified in the 2nd harvest – 0.58, and a strong one in the 3rd – 0.75. Since the HTC indicator includes precipitation and temperature, it is quite evident that the available soil moisture in this case has a stronger impact. Between the duration of the growing season of plants and the sum of active temperatures above 10°C and the yield of dry matter, an average relationship was identified only in the first and third harvests – a correlation coefficient of 0.63 and 0.46, respectively.

Notably, in the first year of life, the root system of alfalfa is not yet sufficiently developed and cannot fully provide plants with the necessary nutrients and moisture, this is also influenced by the genetic characteristics of varieties and hybrid populations (Karta, 2006; Georgieva & Nikolova, 2015) (Fig. 1).

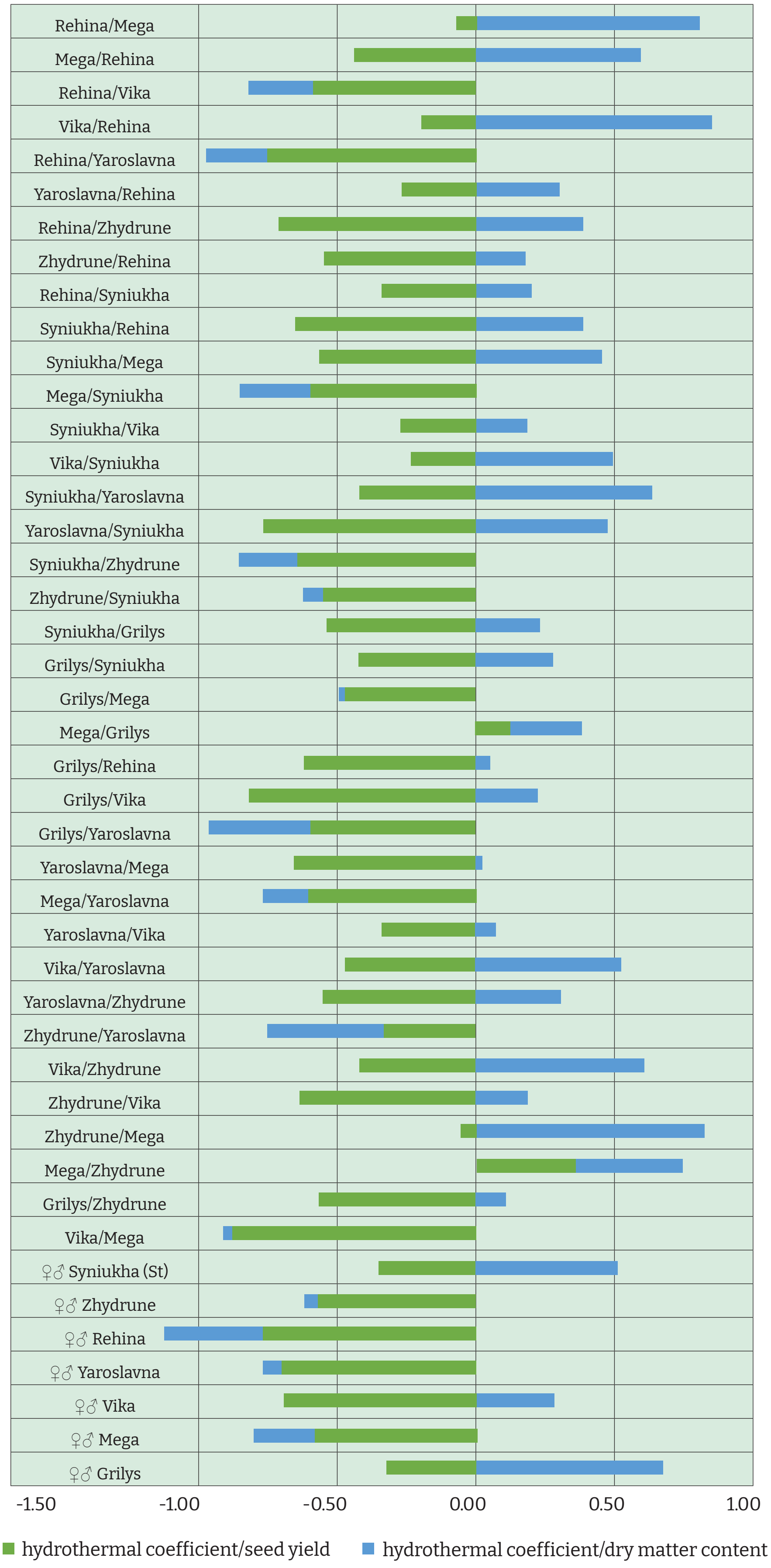

Figure 1. Dependence of the influence of hydrothermal factors on the feed and seed productivity of varieties and hybrids (F_{3-5}) alfalfa seed populations

It was identified that varieties and hybrid populations reacted differently to hydrothermal conditions, among which, as already noted, moisture has the greatest impact. In general, in most cases, a positive reaction was recorded for the dry matter yield. The strongest effect was identified in the samples of Yaroslavna (correlation coefficient was 0.85), Syniukha/Mega (0.82), Grilys (0.8), Regina/Mega (0.68), Yaroslavna/Zhidrune (0.64), Syniukha/Vika (0.61), Mega (0.59). Potentially, these samples can form a fairly high feed productivity on irrigated land. Some populations of alfalfa, on the contrary, reduced the accumulation of vegetative mass with an increase in available moisture, among which the following should be highlighted: Regina/Yaroslavna (-0.46), Vika/Syniukha (-0.43), and Grilys/Syniukha (-0.36).

As for seed productivity, with an increase in the amount of moisture, almost all samples showed a negative effect on the level of the correlation coefficient – from -0.06 to -0.87. Only two hybrid populations showed a positive effect of HTC indicators on the level of seed and feed productivity: Syniukha/Regina (0.36; 0.38) and Grilys/Regina (0.13; 0.25). It was identified that hybrids and varieties decreased the level of seed productivity with fodder growth: Syniukha/Mega (-0.06 and 0.82), Grilys (-0.08 and 0.8), Yaroslavna (-0.2 and 0.85), Zhidrune/Yaroslavna (-0.23 and 0.5), Vika/Zhidrune (-0.28 and 0.18). That is, an inversely proportional relationship was identified, which is important for the development of breeding programmes for creating synthetic alfalfa varieties with increased feed and seed productivity.

In contrast to feed productivity, the formation of the seed crop, in addition to the negative impact of high soil acidity, is influenced by a number of other factors: insufficient supply of nutrients (both macro- and microelements), lack of a sufficient number of pollinating insects, abortivity of flowers and beans, and appropriate hydrothermal conditions (Buhaiov & Horenskyi, 2021; Rudska, 2016; Buhaiov *et al.*, 2018).

It is known that the potential of seed productivity of alfalfa in the Forest-Steppe is only partially realised. This is due to the low level of pollination of flowers (usually 40-60%) and a small number of seeds in the bean (3-4 pcs.), which largely depends on hydrothermal and soil conditions (Bolaños-Aguilara *et al.*, 2002; Katepa-Mupondwa *et al.*, 1996). A brief description of hydrothermal conditions is given in Table 5.

Table 5. Seed yield in hybrid populations (F_3 and F_5) alfalfa sowing and hydrothermal indicators 2013-2020

Years	Precipitation, mm (30 days before flowering)	Precipitation, mm (30 days during flowering)	Total precipitation (30 days before and during flowering) mm	HTC	Precipitation amount (t fact>10°C), mm	Sum of active temperatures (t fact>10), °C	Seed yield, t/ha M±m
2013	62	152	214	1.18	278.2	2365.5	0.352±0.15
2014	135	53	188	1.56	263	1689.3	0.167±0.07
2015	34.3	35	69.3	0.49	89.3	1809.8	0.525±0.15
2016	54	52	106	0.73	186	2557.8	0.231±0.11
2017	15	20	35	0.59	125	2108.2	0.319±0.12
2018	14	186.5	200.5	1.21	302.5	2504.4	0.229±0.08
2019	144	88	232	1.37	278	2032.4	0.093±0.06
2020	136	68	204	1.07	292.4	2724.4	0.211±0.08
Average	74.29	81.81	156.10	1.03	226.80	2223.98	0.258±0.141

Since alfalfa is a cross-pollinated entomophilic crop, and its wild pollinating insects arrange nesting sites mainly in the soil, precipitation during 30 days before and during the flowering of plants (May-June) is considered for analysis, in addition to the factors used in assessing feed productivity. It is this period that is critical for the reproduction of pollinators, thus, accordingly, it directly affects the level of seed yield.

The calculated HTC indicators during the growing season of alfalfa show that in 2015 there was a severe drought; in 2016 and 2017 – average; in 2013, 2018, 2019, and 2020 – there were quite wet conditions, and in 2014 – excessive moisture. The amount of precipitation was 89.3-302.5 mm, of which 57-83% fell in the period of 30 days before and during the flowering of plants. With the exception of 2017, when only 28% of the specified amount, or 35 mm, fell during this period. The sum of active temperatures over the years was 1689.3-2724.4°C.

It was identified that seed yield depended to a greater extent on the amount of precipitation (Table 6).

Table 6. Relationship of alfalfa seed yield with hydrothermal conditions

Parameter	Indicator value
Precipitation 30 days before flowering	-0.64[1]
Average daily temperatures 30 days before flowering	0.19
Precipitation during flowering (30 days)	-0.17
Average daily temperatures during flowering (30 days)	-0.17
Amount of precipitation 30 days before and during flowering	-0.48[1]
Amount of precipitation during the growing season	-0.7[1]
Sum of active temperatures	-0.19
HTC of the reporting year	-0.73[1]
HTC of the previous year	-0.27

Notes: [1] – the correlation is substantial at 0.05

Thus, in 2015, with a precipitation level of 89.3 mm, a seed yield of 0.525 t/ha was obtained, and in 2017 (125 mm) – 0.319 t/ha. In 2013, a sufficient level of yield was also obtained (0.352 t/ha) with very substantial precipitation – 278.2 mm. In such years, the duration of precipitation and the sum of active temperatures during this period are essential.

Other authors (Petrychenko *et al*., 2021; Demydas *et al*., 2010; Tyshchenko & Tyshchenko, 2014) analysed the influence of these factors in general for the entire growing season of alfalfa plants. Moreover, one or more varieties were used as the object of research. According to the results, the dependence of the formation of the leaf-stem mass of 44 varieties and hybrids of alfalfa on the amount of precipitation and temperature was established. The relationship between dry matter yield and seed yield was identified. Most studies, as a rule, are conducted separately for these indicators and, accordingly, their dependencies are not analysed (Tyshchenko *et al*., 2020; Petrychenko *et al*., 2021).

According to the study by Tishchenko (2012), in years with favourable weather conditions, the yield of alfalfa seeds was in the range of 0.67-1.17 t/ha, with unfavourable conditions – 0.17-0.36 t/ha. It was also possible to identify hybrid populations that responded less to the deterioration of environmental conditions and responded well to their improvement and were characterised by high nitrogen-fixing activity. Harvesting the grass stand in the early stages (the beginning of budding) does not allow plants to deposit enough plastic substances in the root crown for regrowth in the next harvest, which leads to a decrease in the density of the grass stand and yield. The flowering phase is crucial for the most intense and sufficient supply of starch and other plastic substances in the root crown.

Zhang (2005) believes that transgenic alfalfa plants can be used in breeding this crop to increase resistance to drought conditions, because due to the increased waxy coating of the leaf cuticle, transpiration decreases, water is better retained in the plant, and therefore slow wilting occurs after watering is stopped and faster and better recovery after watering is resumed. Alfalfa regrowth begins early in spring with buds located on the root crown. The intensity of spring and post-harvest regrowth of alfalfa species and varieties depends on their genotype, nutrient reserves in the plant root crown, soil moisture, and meteorological conditions, and is closely related to plant height.

Tucak *et al.* (2008) consider plant height to be one of the important indirect indicators of feed mass yield. They observed a high association of alfalfa plant height with the yield of green mass and dry matter (g=0.85; 0.87). It was identified that the height of the alfalfa grass stand (the phase of the beginning of flowering) decreases from harvest to harvest, so in the first harvest it was 67-81 cm, in the second – 54-63 cm, in the third – 38-61 cm. Along the harvests, the height of plants largely depended on meteorological conditions and was, as a rule, maximum in the first harvest, reaching 70.6-76.4 cm, and minimum (20.6-31.5 cm) – in the third harvest. Sometimes, in the first year of life, the height of alfalfa plants was lower than in subsequent years, and it naturally increases from the first year of life to the third. The author explains this by saying that in the first year of life, the alfalfa root system is not yet sufficiently developed and cannot provide plants with the necessary nutrients, and the genetic characteristics of populations are also important.

Based on the results of the study, the relationship between dry matter and seed yields with indicators of hydrothermal conditions was established. Thus, the conducted studies indicate the specific features of the influence of precipitation and temperature on the formation of leaf-stem mass in separate harvest cycles.

CONCLUSIONS

Based on the results of the assessment (2013-2020), the influence of hydrothermal indicators of the growing zone on the feed and seed productivity of alfalfa for different years of use of the herbage was established. It is identified that the formation of maximum indicators of dry matter yield in a particular harvest and seed yield is influenced by both the hydrothermal resources of the region and the biological characteristics of varieties and hybrids. This is confirmed by the corresponding correlation coefficients. Thus, the amount of precipitation from the beginning of the relative rest period to the onset of active temperatures above 10°C had the greatest impact on the formation of the leaf-stem mass of the 1st harvest; the amount of precipitation during the time after the establishment of active temperatures above 10°C and before accounting for the leaf-stem mass moderately affected the formation of the 2nd harvest and strongly – the 3rd; the amount of precipitation during the previous harvest – the 2nd-4th harvests (the strongest – the 4th); the sum of active temperatures above 10°C – the 1st and 3rd harvests; the HTC indicator – the 2nd and 3rd; duration of the growing season with active temperatures above 10°C – the 1st and 3rd harvests.

In contrast to feed productivity, seed yield largely depended on the amount of precipitation before the flowering phase and in general during the growing season of alfalfa. Accordingly, the lower the value of the HTC indicator, the more likely it is to get a high seed yield from the first harvest. Thus, the complexity of breeding alfalfa is confirmed, when the opposite conditions of the year accordingly affect plant productivity – excessive and sufficient moisture increases the level of feed productivity, while seed productivity decreases. Arid and insufficiently humid conditions, on the contrary, contributed to the formation of seeds, while reducing the yield of leaf-stem mass.

The identified features of the formation of leaf-stem mass and seeds of varieties and hybrids depending on the hydrothermal parameters of the growing area encourage further research on this subject. In particular, identifying the relationship between the yield of dry matter and the yield of seeds from the grass stand of the second harvest, since this technological agricultural approach is widely used in practice.

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Вплив гідротермічних факторів на кормову та насіннєву продуктивність люцерни посівної в умовах Лісостепу Правобережного

Анотація. Актуальність дослідження зумовлена необхідністю вивчення впливу гідротермічних ресурсів регіону на формування врожаю листостеблової маси та насіння люцерни посівної, що є важливим за умов сучасних змін клімату. У зв'язку з цим дана стаття спрямована на виявлення впливу опадів і температурного режиму на ріст і розвиток рослин сортів і гібридів за циклами скошування та роками використання травостою. В процесі дослідження використано методи: польовий (проведення фенологічних спостережень та обліків), лабораторний (структурний аналіз травостою), математично-статистичний (об'єктивна оцінка одержаних експериментальних даних). З'ясовано, що кількість опадів від початку періоду відносного спокою до настання активних температур вище 10 °C мала найбільший вплив на формування 1-го укосу; сума опадів після встановлення активних температур вище 10 °C і до обліку урожаю листостеблової маси помірно впливала на формування 2-го укосу та сильно – на 3-й; сума опадів попереднього укосу – на 2-4-й укіс (найсильніше – на 4-й); сума активних температур вище 10 °C – на 1-й та 3-й укоси; показники гідротермічного коефіцієнту – на 2-3-й; тривалість вегетаційного періоду з активними температурами вище 10 °C – на 1-й і 3-й укоси. Урожайність насіння, на відміну від кормової продуктивності, значною мірою залежала від суми опадів перед фазою цвітіння та в цілому під час вегетації люцерни посівної. Встановлено, що на вихід сухої речовини та урожайність насіння мають вплив: сума активних температур, кількість опадів за укіс чи вегетацію рослин та генетичні особливості досліджуваних гібридів і сортів. Виявлено, що гідротермічні умови року по-різному впливають на рівень продуктивності рослин – надлишкове і достатнє зволоження підвищує кормову продуктивність та зменшує урожайність насіння. Практичну цінність одержані дані становлять для прогнозування врожаю зеленої маси люцерни посівної кожного наступного укосу травостою залежно від суми опадів впродовж вегетації попереднього, а також для розробки програм створення сортів-синтетиків з підвищеними показниками урожайності листостеблової маси та насіння

Ключові слова: гібрид, гідротермічний коефіцієнт, цикл скошування, вихід сухої речовини, урожайність насіння, кореляція