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VARIABILITY OF SOYBEAN YIELD AND SEED QUALITY DEPENDING ON ENVIRONMENTAL HYDROTHERMAL FACTORS

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Relative humidity was established to play a leading positive role for the soybean yield (r = 0.723). A mathematical model of the dependence of soybean yield on hydrothermal environmental conditions was constructed. The total protein and oil content in seeds was determined by protein content (r = 0.948) and did not depend on oil content (r = -0.091). There was a medium negative correlation between protein content and relative humidity (r = -0.582) and between protein content and average air temperature (r = -0.437); there was also a weak correlation between protein content and precipitation amount (r = -0.213). The oil content in seeds was positively correlated with the average temperature (r = 0.435) and relative humidity (r = 0.376). The protein and oil output was positively correlated with relative humidity (r = 0.686) and precipitation amount (r = 0.603).

Key words*: soybean, yield, mathematical model, seed quality, correlation, variety trial, environmental factors.*

Introduction. Soybean is a leading crop in the global agriculture, playing a significant role in the agrarian sector of Ukraine. The soybean production in Ukraine has gone from coming into being and adapting to local conditions from the late 1990s to a clear upward trend in the sown areas and yields in the 21st century. In the world ranking of soybean producers, Ukraine ranks first in Europe and eighth-tenth in the world. Due to the soybean processing industry coming-to-be in Ukraine since the beginning of the 21st century, the soybean complex, which has great prospects and consequences for the agricultural economy and the state as a whole, is rapidly forming [1].

Literature review andproblem articulation. The soybean yield capacity in production is not fully used, although the crop potential is far from exhausted. To increase the soybean yields, it is necessary to improve the breeding process basing on increased yield, adaptability and seed quality of breeding material and new varieties. These issues are especially relevant in the context of global and local climatic changes. To further successfully enhance the soybean production, not only the economically feasible level of yield, but also the maximization of the crop potentials with the fullest use of soil and climatic resources of a growing location is topical. The soybean yield potential realization stability in production is determined by the crop adaptability in dynamic environmental conditions. Recently, this problem has been especially exacerbated due to increased frequencies of bio- and abiotic environmental stressors.

Environmental factors significantly affect soybean yields. Relationships between the plant performance and major components of the yield structure and biological characteristics are greatly modified by environmental factors [2−9]. When selecting high-yielding genotypes, one has to deal with phenotypic variability, which is determined both by genetically determined level of a trait and by fluctuations in growing conditions. The correctness of genotype identification by phenotype depends on the value of the latter [10].

Experiments to assess the plasticity and stability of soybean varieties in terms of yield showed inverse correlations between yield and temperature sum (r = -0.849) and between yield and precipitation amount (r = -0.307), indicating the need for optimal hydrothermal ratio to achieve high yields [11] .

Studies of expression of genetically determined traits and dependences of their levels on environmental conditions are of both theoretical and practical importance in plant breeding [12].

Purpose and objectives. Our purpose was to establish patterns of influence of the hydrothermal mode on the yield and seed quality of soybean breeding material and varieties in the Eastern Forest-Steppe of Ukraine and to determine the variability of traits under the influence of environmental factors.

Materials and methods. Varieties and breeding accessions of the 2008–2018 competitive variety trials (CVTs) in the amount of 60 to 153 were taken as material to assess the effects of the hydrothermal mode on the yield. The impact of the hydrothermal environmental factors during the soybean growing period (April-September) on the performance (yield and protein and oil output per unit area) and seed quality (protein and oil content in seeds) was studied in 50 CVT soybean accessions in 2011−2017.

Soybeans were grown in compliance with the technology typical for the study location in four replications; the plot area was 25 m^2. The dependence of variability of yield and quality on the hydrothermal environmental factors during the growing period was determined by correlation analysis in STATISTICA 10. To build a dependence model for soybean yield against relative humidity and average air temperature, we used mathematical modeling.

Results and discussion. Investigation of the dependence of the average yield of soybeans on the main hydrothermal factors of the environment showed the following patterns. Correlation analysis revealed the relationship between the average yield and hydrothermal parameters of the entire growing period (April−September) and its first (April−June) and second (July−September) halves (Table 1).

Table 1

Correlation coefficients between soybean yield and hydrothermal factors (competitive variety trials, average for 2008–2018)

Factor	Yield, t/ha		
	Period		
	April−September	April−June	July–September
Relative air humidity, %	0.712*	0.298*	0.709*
Precipitation amount, mm	0.468*	0.483*	0.348*
Average air temperature, ^{o}C	-0.266*	-0.185*	-0.139*
Effective temperature sum, ^{o}C	0.081	0.019	-0.270*

Note: * − significant values.

Thus, in general, the yield was most closely correlated with relative air humidity (r = 0.712) and precipitation amount (r = 0.468) during the growing period, which makes these environmental factors be determinants for soybean yields. There was an insignificant negative correlation between yield and average air temperature (r = -0.266). The yield was not correlated with the effective temperature sum (insignificant r = 0.081).

Analysis of the correlation coefficients between yield and hydrothermal parameters for the entire growing period and its first and second halves showed some differences in their relationship with yield.

The relationship of yield with relative air humidity in the first half of the growing period was weaker than in the whole period (r = 0.298), and did not change significantly with other environmental factors.

The relationship of yield with relative air humidity in the second half of the growing period got stronger (r = 0.709) and became similar to that for the entire growing period (r =

0.712). During the second half of the growing period, the negative impact of the effective temperature sum also increased (insignificant ($r = 0.081$) for the entire growing period and $r = 0.270$ for the second half of the growing period).

The strong relationship between yield and relative air humidity confirms the fact that air humidity is important for water balance, affecting the intensity of evaporation from the soil surface and transpiration [13]. The relative humidity of ground air rises with decreasing temperature and drops with increasing temperature. The soybean, as a crop which evolved in a monsoon climate, has increased requirements for water and heat [14−16]. Therefore, relative humidity, as an integral indicator of wetting, has the most significant impact on yield. The role of relative air humidity increases in the second half of the growing period. The generative period is the most vital for seed productivity of the crop; it is during this period that soybean plants form significant numbers of flowers, ovaries and pods [17].

Mathematical modeling is used to construct a model for the dependence of soybean yield on the main hydrothermal environmental factors − relative air humidity and average air temperature during the soybean growing period (April−September) (Fig. 1).

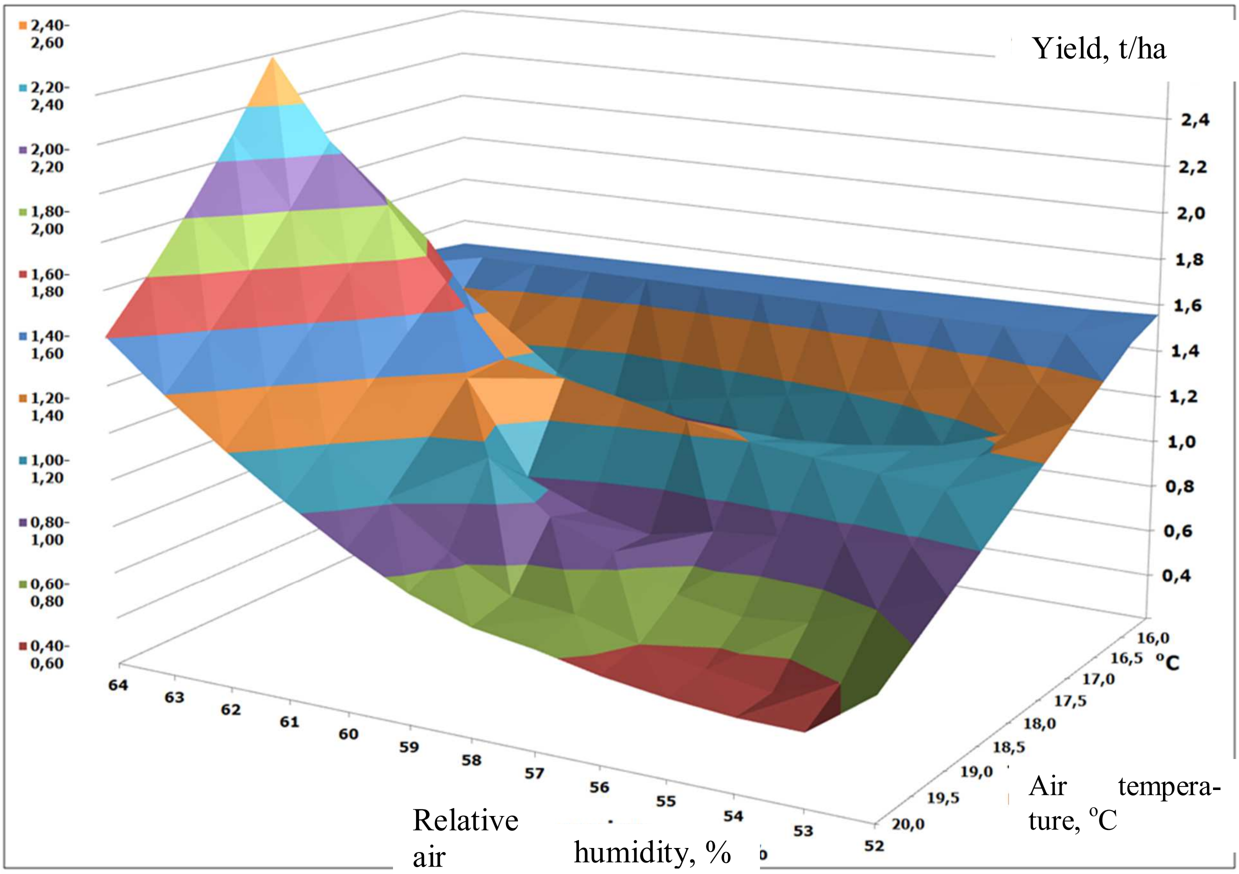

Fig. 1. Mathematical model of the dependence of soybean yield on relative air humidity and average air temperature (competitive variety trials, average for 2008–2018)

According to the mathematical model, the lowest yield (0.40−0.60 t/ha) is observed at the maximum average air temperature (20.0°C) and the minimum relative humidity (52%). A rise in the relative air humidity up to 64% at the maximum air temperature leads to an increase in the yield to 1.40–1.60 t/ha. At the minimum relative air humidity, a rise in the air temperature significantly reduces the yield: from 1.40-1.60 t/ha to 0.40-0.60 t/ha. This indicates that wetting offsets the negative impact of high temperatures on the yield and has no effect on the yield at low temperatures.

At the minimum average air temperature and increased relative air humidity, no significant gain in the yield was observed (it ranged 1.40 to 1.60 t/ha).

Therefore, combinations of optimal levels of average air temperature and relative air humidity are asspciated with a significant gain in the soybean yield. The highest yield was achieved by combining moderate air temperature and high relative humidity. According to the mathematical model, the determining factors for the soybean yield are relative air humidity and an optimal for the crop air temperature (18.0−18.5^{o}C).

Analysis of the effects of several factors on the biochemical parameters of soybean seeds showed that the environment was the most important source of variability in the protein and oil content [18]. The protein and oil content in soybean seeds is subject to high genotypic and modification variability and depends on the cultivation region, genotype, ripeness group, application of various farming techniques and other factors. At the same time, in different regions of the globe, the climate has a much greater influence on the protein content in seeds than on the oil content [19, 20, 21], and both of these characteristics vary significantly depending on growing conditions [18, 22, 23]. Ukrainian scientists believe that breeding plays the primary direct role in improving the quality of soybean seeds [24, 25, 26].

Information about the dependence of the protein content in seeds on the yield is contradictory. Some researchers think that increasing seed yields by optimizing growing conditions is accompanied by an increase in protein content [27], while others argue that the combination of high yields and protein content in soybean seeds depends significantly on meteorogical conditions [28].

The oil content in soybean seeds was positively correlated with yield [15]. The oil content in soybean seeds responded positively to hot and humid weather (r = 0.870 and r = 0.610, respectively) [29].

There was a positive correlation between yield and wetting factors: relative air humidity (r = 0.723) and precipitation amount during the growing period (r = 0.605). In contrast, the thermal factors were negatively correlated with yield. There was a moderate negative correlation between yield and average air temperature (r = -0.666). There was a weaker correlation between yield and the efective temperature sum (r = -0.373).

There are different opinions about relationships between yield and protein content. Some researchers claim that there is a strong correlation between yield and protein content in seeds [30]. Others emphasize inverse (negative) relationship between seed yield and quality. There was an inverse correlation between the content of protein and oil in seeds (r = -0.020 – -0.470) as well as between yield and protein content in seeds (r = -0.538), which complicates the breeding of productive and high quality genotypes [31].

In our study, the yield determined the protein and oil output from 1 ha (r = 0.994), had no significant relationship with protein content (insignificant r = -0.106) and had weak negative correlations with oil content (r = -0.220) and the total content of protein and oil (r = -0.192).

A moderate negative correlation (r = -0.403) was recorded between the protein and oil contents. The total content of protein and oil in seeds was determined by protein content (r = 0.948) and did not depend on oil content (insignificant r = -0.091). There were moderate negative correlations between protein content and relative humidity (r = -0.582) and between protein content and average air temperature (r = -0.437) and a weak negative correlation between protein content and precipitation amount (r = -0.213). The oil content in seeds was positively correlated with average temperature during the growing period (r = 0.435) and relative air humidity (r = 0.376). The output of protein and oil did not depend on protein content (insignificant r = -0.006) and was negatively correlated with oil content (r = -0.223). The total content of protein and oil in seeds was negatively affected by relative humidity (r = -0.502), average air temperature (r = -0.325), and precipitation amount (r = -0.175) (Table 2).

The output of protein and oil, like yield, was positively correlated with wetting factors (relative humidity air (r = 0.686) and precipitation amount (r = 0.603)) and negatively correlated with thermal factors (average air temperature (r = -0.706) and the effective temperature sum (r = -0.362).

Table 2

Correlation coefficients between the economic characteristics of soybeans and hydrothermal factors of the growing period (April−September), (competitive variety trials, average for 2011−2017)

Parameter	Yield, t/ha	Content in seeds, %			Output of protein and oil, t/ha
		protein	oil	protein + oil	
Protein content in seeds, %	-0.106	–	–	–	–
Oil content in seeds, %	-0.220*	-0.403*	–	–	–
Protein and oil content in seeds, %	-0.192*	0.948*	-0.091	–	–
Output of protein and oil, t/ha	0.994*	-0.006	-0.223*	-0.084	–
Relative air humidity, %	0.723*	-0.582*	0.376*	-0.502*	0.686*
Precipitation sum, mm	0.605*	-0.213*	0.163	-0.175*	0.603*
Average air temperature, ^{o}C	-0.666*	-0.437*	0.435*	-0.325*	-0.706*
Effective temperature sum, ^{o}C	-0.373*	0.078	0.078	0.112	-0.362*

Note: * − significant values.

There were some differences in the correlations between the environmental factors during the entire growing period and the economic characteristics and between the environmental factors separately during the first and second halves of the soybean growing period and the economic features. We investigated the influence of the hydrothermal environmental factors during the first part of the soybean growing period (April−June), when vegetative mass is formed, on seed productivity and quality and showed that the average air temperature had no negative impact on yield (insignificant r = -0.175), unlike the average air temperature during the entire growing period, which negatively affected this indicator (r = -0.666). The protein content in seeds was moderately positively correlated with relative air humidity (r = 0.347) and precipitation amount (r = 0.501) during the first half of the growing period (Table 3).

Table 3

Correlation coefficients between the economic characteristics of soybeans and hydrothermal factors of the first half of the growing period (April−June), (competitive variety trials, average for 2011−2017)

Parameter	Yield, t/ha	Content in seeds, %			Output of protein and oil, t/ha
		protein	oil	protein + oil	
Protein content in seeds, %	-0.106	–	–	–	–
Oil content in seeds, %	-0.220*	-0.403*	–	–	–
Protein and oil content in seeds, %	-0.192*	0.948*	-0.091	–	–
Output of protein and oil, t/ha	0.994*	-0.006	-0.223*	-0.084	–
Relative air humidity, %	0.687*	0.347*	-0.526*	0.195*	0.718*
Precipitation sum, mm	0.525*	0.501*	-0.216*	0.470*	0.591*
Average air temperature, ^{o}C	-0.078	-0.737*	0.573*	-0.603*	-0.140
Effective temperature sum, ^{o}C	-0.210*	-0.601	0.614*	-0.440*	-0.253*

Note: * − significant values.

The negative effects of the average air temperature and the effective temperature sum during the first half of the growing period on the protein content were stronger (r = -0.737 and r =

-0.601, respectively) than during the entire growing period. The oil content in seeds was negatively affected by relative air humidity (r = -0.526) and precipitation amount (r = -0.216), and positively affected by effective temperature sum (r = 0.614) in the first half of the growing period. The wetting factors were positively correlated with the total content of protein and oil: relative humidity (r = 0.195) and precipitation amount (r = 0.470). The average air temperature and the effective temperature sum during the first half of the growing period had negative effects on the total content of protein and oil in seeds (r = -0.603 and r = -0.440, respectively). There was a weaker negative correlation between the output of protein and oil and the average air temperature in the first half of the growing period (r = -0.140).

In the second half of the growing period, the generative organs of soybeans are formed, major biochemical components of seeds are synthesized and accumulated, seeds set, fill and ripen. This determines the peculiarities of correlations between the yield and seed quality indicators and the environmental factors (Table 4).

Table 4

Correlation coefficients between the economic characteristics of soybeans and hydrothermal factors of the second half of the growing period (July−September), (competitive variety trials, average for 2011−2017)

Parameter	Yield, t/ha	Content in seeds, %			Output of protein and oil, t/ha
		protein	oil	protein + oil	
Protein content in seeds, %	-0.106	–	–	–	
Oil content in seeds, %	-0.220*	-0.403*	–	–	–
Protein and oil content in seeds, %	-0.192*	0.948*	-0.091	–	–
Output of protein and oil, t/ha	0.994*	-0.006	-0.223*	-0.084	–
Relative air humidity, %	0.829*	-0.495*	0.234*	-0.457*	0.798*
Precipitation sum, mm	0.342*	-0.805*	0.449*	-0.719*	0.273*
Average air temperature, ^{o}C	0.030	0.787*	-0.744*	0.597*	0.091
Effective temperature sum, ^{o}C	-0.115	0.829*	-0.688*	0.663*	-0.049

Note: * − significant values.

The effect of relative air humidity in the second half of the growing period on the yield got stronger (r = 0.829); the precipitation effect – weaker (r = 0.342); and the effects of air temperature and effective temperature sum were negligible for the yield (insignificant r = 0.030 and r = -0.115, respectively).

Publications indicate that high oil content is observed at high humidity and relatively low temperatures, while a high protein content – in dry and hot weather [15, 16, 32]. It was shown that temperature had a greater influence on synthesis and accumulation than wetting. Protein is better accumulated under stable heat during the seed filling and ripening phase. In our experiments, the protein content was strongly negatively correlated with precipitation amount in the second half of the growing period (r = -0.805), moderately correlated with relative air humidity (r = -0.495), and strongly positively correlated with the average air temperature (r = 0.787) and effective temperature sum (r = 0.829).

The effect of relative air humidity in the second half of the growing period on the oil content in seeds got weaker (r = 0.234) while the precipitation amount effect got stronger (r = 0.449). The effects of the average temperature and of the effective temperature sum in the second half of the growing period on the oil content became strong negative (r = -0.744 and r = -0.688, respectively). The total content of protein and oil, which is determined by protein content (r = 0.948), was negatively correlated with relative air humidity (r = -0.457), precipitation amount (r = -0.719) and positively correlated with the average air temperature (r = 0.597) and effective temperature sum (r = 0.663) in the second half of the growing period. The output of protein and oil from 1 ha, which is determined by yield (r = 0.994), depended strongly on relative air humidity (r = 0.798) and was weakly correlated with precipitation amount (r = 0.273).

Thus, the analysis of the relationships between the economic characteristics and hydrothermal factors of the environment revealed certain patterns. There was a strong positive correlation between yield and relative air humidity (r = 0.723). The influence of this factor in the second half of the growing period, during yield formation, increased (r = 0.829) compared to the first period (r = 0.687). The dependence of yield on precipitation amount was moderate (r = 0.605). The role of precipitation was stronger in the first half of the growing period (r = 0.525) compared to its second part (r = 0.342). A moderate negative correlation was found between yield and average air temperature during the entire growing period (r = -0.666). There was no relationship between this factor and yield in the first and second halves of the growing period (insignificant r = -0.078 and r = -0.030, respectively). The same trend was noted in relation to the influence of the sum of effective temperatures on soybean yield. The correlation coefficient between yield and the sum of effective temperatures during the entire growing period was -0.373; the correlation coefficient between yield and temperature sum in the first part of the growing period was -0.210; and the correlation coefficient between yield and temperature sum in the second part of the growing period was insignificant (r = -0.115).

Conclusions. We demonstrated a leading role of relative air humidity for soybean yield (r = 0.723). The effect of relative air humidity during yield formation (July–September) got stronger (r = 0.829) compared to the first part of the growing period (April–June) (r = 0.687). The dependence of yield on precipitation amount during the growing period was moderate (r = 0.605). The role of precipitation increased in the first half of the growing period (r = 0.525) compared to the second half (r = 0.342). There was a moderate negative correlation between yield and average air temperature (r= -0.666) as well as between yield and the sum of effective temperatures during the growing period (r = -0.373). A mathematical model of the dependence of soybean yield on the hydrothermal factors was constructed. There was a moderate negative correlation (r = -0.403) between the contents of protein and oil. The total content of protein and oil in seeds was determined by protein content (r = 0.948) and did not depend on the oil content (insignificant r = -0.091). The protein content was moderately negatively correlated with relative air humidity (r = -0.582) and average air temperature (r = -0.437) and weakly correlated with precipitation amount (r = -0.213). The oil content in seeds was positively correlated with the average temperature during the growing period (r = 0.435) and relative air humidity (r = 0.376). The output of protein and oil did not depend on protein content (insignificant r = -0.006) and was negatively correlated with oil content (r = -0.223). The total content of protein and oil in seeds was negatively affected by relative humidity (r = -0.502), average air temperature (r = -0.325), and precipitation amount (r = -0.175). The output of protein and oil was positively correlated with relative air humidity (r = 0.686) and precipitation amount (r = 0.603) and negatively correlated with the average air temperature (r = -0.706) and effective temperature sum (r = -0.362). There were some differences in the correlations between the environmental factors during the entire growing period and the economic characteristics and between the environmental factors separately during the first and second halves of the soybean growing period and the economic features.

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ЗАКОНОМІРНОСТІ МІНЛИВОСТІ ВРОЖАЙНОСТІ ТА ЯКОСТІ НАСІННЯ СОЇ ЗАЛЕЖНО ВІД УПЛИВУ ГІДРОТЕРМІЧНИХ ЧИННИКІВ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

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Мета і задачі дослідження. Метою дослідження є встановлення закономірностей упливу гідротермічного режиму довкілля на показники врожайності та якості насіння сої у східному Лісостепу України, визначення мінливості ознак під впливом чинників середовища.

Матеріали і методи дослідження. Матеріалом були сорти та селекційні номери конкурсного сортовипробування 2008–2018 рр. у кількості від 60 до 153 зразків. Технологія вирощування типова для зони, повторність–чотириразова, площа ділянки 25 м^2. Залежність мінливості ознак урожайності і якості насіння сої від гідротермічних чинників визначали за допомогою кореляційного аналізу та методу математичного моделювання.

Обговорення результатів. За період вегетації найбільш тісний зв'язок урожайність насіння сої мала із відносною вологістю повітря (r=0,712) та сумою опадів (r=0,468). Між урожайністю і середньою температурою повітря встановлено неістотний негативний зв'язок (r=-0,266). Із сумою ефективних температур урожайність не мала зв'язку (r=0,081). Найменший рівень урожайності (0,40–0,60 т/га) спостерігається при максимальних значеннях середньої температури (20,0 ^{o}C) і відносної вологості повітря (52 %). Зростання відносної вологості повітря до 64 % при максимальній температурі призводить до підвищення врожайності до рівня 1,40–1,60 т/га. При мінімальній відносній вологості повітря, зростання температури суттєво зменшує врожайність – від 1,40–1,60 т/га до 0,40–0,60 т/га. Найвища врожайність, згідно математичної моделі, досягалась при сполученні середнього рівня температури (18,0–18,5 ºC) і високого рівня відносної вологості повітря (64 %). Урожайність насіння визначала збір білка та олії з 1 га (r=0,994), не мала істотного зв'язку з вмістом білка (неістотний r=-0,106) і мала слабкий негативний зв'язок із умістом олії (r=-0,220) та сумарним умістом білка і олії (r = -0,192). Між умістом білка і олії зафіксована середня негативна кореляція (r = -0,403). Сумарний уміст білка та олії в насінні визначається вмістом білка (r = 0,948) і не залежить від умісту олії (r = -0,091). Уміст білка мав середній негативний зв'язок із відносною вологістю (r = -0,582) та середньою температурою повітря (r = -0,437) та слабкий зв'язок із сумою опадів (r = -0,213). Уміст олії в насінні мав позитивні зв'язки із середньою температурою за період вегетації (r = 0,435) та відносною вологістю повітря (r = 0,376). Збір білка та олії не залежав від умісту білка (неістотний r = -0,006) і має негативну кореляцію із умістом олії (r = -0,223). На сумарний вміст в насінні білка і олії негативно впливали відносна вологість (r = -0,502) та середня температура повітря (r = -0,325) і сума опадів (r = -0,175). Збір білка і олії, як і врожайність, позитивно корелював із чинниками зволоження – відносною вологістю повітря (r = 0,686) та сумою опадів (r = 0,603), і мав негативний зв'язок із термічними факторами – середньою температурою повітря (r = -0,706) та сумою ефективних температур (r = -0,362). Установлено певні відмінності кореляцій між чинниками довкілля та господарськими ознаками загалом за весь період вегетації та окремо за першу (квітень–червень) та другу (липень–вересень) половини періоду вегетації сої.

Висновки. Визначено провідну роль відносної вологості повітря у формуванні врожайності сої. Залежність урожайності від суми опадів за період вегетації була середньою, роль опадів зростала у першій половині вегетації (r = 0,525) порівняно із другою половиною (r = 0,342). Між урожайністю та середньою температурою повітря спостерігався середній негативний зв'язок (r = -0,666), як і між урожайністю та сумою ефективних температур за період вегетації (r = -0,373). Між умістом білка і олії була середня негативна кореляція (r = -0,403). Сумарний уміст білка та олії в насінні визначається вмістом білка (r = 0,948) і не залежить від

умісту олії (r = -0,091). Збір білка та олії не залежав від умісту білка (r = -0,006) і мав негативну кореляцію із умістом олії (r = -0,223). На сумарний вміст у насінні білка і олії негативно впливали відносна вологість (r = -0,502), середня температура повітря (r = -0,325) і сума опадів (r = -0,175). Збір білка і олії позитивно корелював із відносною вологістю повітря (r = 0,686) та сумою опадів (r = 0,603) і мав негативний зв'язок із середньою температурою повітря (r = -0,706) та сумою ефективних температур (r = -0,362). Побудовано математичну модель залежності врожайності сої від гідротермічних умов довкілля.

Ключові слова: *соя, урожайність, математична модель, якість насіння, кореляція, сортовипробування, чинники довкілля.*

VARIABILITY OF SOYBEAN YIELD AND SEED QUALITY DEPENDING ON ENVIRONMENTAL HYDROTHERMAL FACTORS

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Purpose and objectives. Our purpose was to establish patterns of influence of the hydrothermal mode on the soybean yield and seed quality in the Eastern Forest-Steppe of Ukraine and to determine the variability of traits under the influence of environmental factors.

Materials and methods. Varieties and breeding accessions of the 2008–2018 competitive variety trials in the amount of 60 to 153 were taken as the test material. Soybeans were grown in compliance with the technology typical for the study location in four replications; the plot area was 25 m^2. The dependence of variability of yield and quality on the hydrothermal environmental factors was determined by correlation analysis and mathematical modeling.

Results and discussion. During the growing period, the soybean yield was most closely correlated with relative air humidity (r = 0.712) and precipitation amount (r = 0.468). There was an insignificant negative correlation between yield and average air temperature (r = -0.266). The yield was not correlated with the sum of effective temperatures (r = 0.081). The lowest yield (0.40-0.60 t/ha) was observed at the maximum values of average air temperature (20.0^{o}C) and air relative humidity (52%). When the relative air humidity rose to 64% at the maximum temperature, the yield increased to 1.40-1.60 t/ha. At the minimum relative air humidity, a rise in temperature significantly reduced the yield: from 1.40-1.60 t/ha to 0.40-0.60 t/ha. The highest yield, according to the mathematical model, was achieved by combining moderate temperature (18.0–18.5^{o}C) and high relative air humidity (64%). The seed yield determined the output of protein and oil from 1 ha (r = 0.994), had no significant relationship with protein content (insignificant r = -0.106) and was weakly negatively correlated with oil content (r = -0.220) and the total content of protein and oil (r = -0.192). There was a moderate negative correlation (r = -0.403) between protein and oil contents. The total content of protein and oil in seeds was determined by protein content (r = 0.948) and did not depend on oil content (r = -0.091). The protein content was moderately negatively correlated with relative humidity (r = -0.582) and average air temperature (r = -0.437) and weakly correlated with precipitation amount (r = -0.213). The oil content in seeds was positively correlated with the average temperature during the growing period (r = 0.435) and relative air humidity (r = 0.376). The output of protein and oil did not depend on protein content (insignificant r = -0.006) and was negatively correlated with oil content (r = -0.223). The total content of protein and oil in seeds was negatively affected by relative humidity (r = -0.502), average air temperature (r = -0.325), and precipitation amount (r = -0.175). The output of protein and oil, like yield, was positively correlated with wetting factors (relative air humidity (r = 0.686) and precipitation amount (r = 0.603)) and negatively correlated with thermal factors (average air temperature (r = -0.706) and the sum of effective temperatures (r = -0.362)). There were some differences in the correlations between the environmental factors during the entire growing period and the economic characteristics

and between the environmental factors separately during the first (April-June) and second (July-September) halves of the soybean growing period and the economic features.

Conclusions. We demonstrated a leading role of relative air humidity for soybean yield (r = 0.723). The dependence of yield on precipitation amount during the growing period was moderate (r = 0.605). The role of precipitation increased in the first half of the growing period (r = 0.525) compared to the second half (r = 0.342). There was a moderate negative correlation between yield and average air temperature (r= -0.666) as well as between yield and the sum of effective temperatures during the growing period (r = -0.373). There was a moderate negative correlation (r = -0.403) between the contents of protein and oil. The total content of protein and oil in seeds was determined by protein content (r = 0.948) and did not depend on oil content (r = -0.091). The protein content was moderately negatively correlated with relative air humidity (r = -0.582) and average air temperature (r = -0.437) and weakly correlated with precipitation amount (r = -0.213). The oil content in seeds was positively correlated with the average temperature during the growing period (r = 0.435) and relative air humidity (r = 0.376). The output of protein and oil did not depend on protein content (insignificant r = -0.006) and was negatively correlated with oil content (r = -0.223). The total content of protein and oil in seeds was negatively affected by relative humidity (r = -0.502), average air temperature (r = -0.325), and precipitation amount (r = -0.175). The output of protein and oil was positively correlated with relative air humidity (r = 0.686) and precipitation amount (r = 0.603) and negatively correlated with the average air temperature (r = -0.706) and effective temperature sum (r = -0.362). A mathematical model of the dependence of soybean yield on the hydrothermal factors was constructed.

***Key words**: soybean, yield, mathematical model, seed quality, correlation, variety trial, environmental factors.*

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ADAPTABILITY OF WINTER BREAD WHEAT BY ENVIRONMENTAL PLASTICITY AND STABILITY

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The results of studying the adaptability of winter bread wheat in terms of environmental plasticity and stability are presented. It was determined that the highest genetic potential of adaptability (sum of ranks 2) in combination with high yields was intrinsic to mid-tall domestic genotypes − Haiok (ε_i = 2.24; R_i = 0.97) and MIP Lada (ε_i = 0.90; R_i = 0.92) (UKR).

***Key words:** adaptability, winter bread wheat, genotypic effect, stability, plasticity, freeze tolerance, yield, source*

Introduction. To successfully intensify winter cereal production, creation of high-yielding and adapted to certain growing conditions plant varieties is a very important step. The introduction of such accessions in combination with high quality grain is a key to their effective implementation. Increased adaptability of winter bread wheat varieties giving stable yields under stressful growing conditions is a major objective of current breeding, which boosts gross yields and stabilizes grain production and, consequently, food security [1, 2]. Preliminary selection of sources of desirable traits and appropriate levels of their expressions under envi-