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Wybrane Zagadnienia Szeroko Pojętej Inżynierii Procesowej

pod redakcją
Andrzeja Gawdzika

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EFFECT OF MAIN METEOROLOGICAL FACTORS AND TIME OF SPRING VEGETATION RECOVERY ON THE DEVELOPMENT AND YIELD OF WINTER GRAIN CROPS IN UKRAINE

Abstract. Research results of the effect of time of spring vegetation recovery of winter wheat on yield are described. It has been established that main effectors include the rainfall sum during the third decade period of August and all September, as well as condition of wintering conditions and the amount of moisture reserves formed during winter , and also the sum of active temperatures > 5º during the period from spring vegetation recovery to heading. The date of spring vegetation recovery may contribute to the establishment of natural laws of changes of favourable and unfavourable years. It could, in turn, allow to soften unfavourable effect of weather factors on winter wheat yield using agrotechnic measures. In subzone of sufficient moisture, the major weather factors that limit the yield of winter barley include the number of days with temperatures below minus 15 ° C, precipitation in September, which forms moisture reserves at the time of sowing, and June precipitation, when grain formation and filling occurs. In subzone unstable moisture, for prediction of the yield of winter barley it is also necessary to take into account the duration of the frost period with temperatures below minus 15 ° C.

Key words: abiotic factors, agrotechnic, spring vegetation recovery.

Problem setting

Ensuring of high and stable yields of winter wheat is one of the high priority tasks of crop growing. It is especially important under conditions of Ukraine since grain is a strategic product, which can compete in the world market and, therefore, can also be a powerful generator for domestic economy.

To a large extent the size and stability of grain yield is achieved using a high level of agricultural technology. However it is also necessary to take into account the cumulative effects of weather factors on crop productivity. They can lead to significant consequences, either positive or negative, even if there was sufficient agronomic and resource supply for cultivation technology.

Analysis of main researches and publications

It is generally known that the level of agricultural technology largely determines the productivity of crops. There is information that under extensive agriculture the soil-climatic factors influence the yield in the following way: natural fertility – 40%, weather – 20%, fertilizers – 10%. Under intensive agriculture this proportion is distributed respectively as: natural fertility – 10%, weather – 10%, fertilizers – 30% [1]. Depending on the region of growing, the effect of agrotechnical components can change, but regardless of that, the techniques of soil cultivation and fertilizers soften the influence of natural factors. In turn, the main climatic factors include moisture resources, sum of temperatures during May-July period and hydrothermal coefficient value [2, 3-4].

Plant reaction on effect of abiotic factors is represented not only by yield, which is an effective sign, but also by the dynamics of their development periods. Duration of interphase periods significantly influences the yield. It was indicated that an increase in duration of grain formation and ripening for 9 days provided yield increase by 11 centner/ hectare [5].

Winter wheat is influenced by factors of all seasons, therefore the termination timing of the autumn vegetation effects the yield formation. In case of early vegetation termination, the yield may be reduced. It is very important for correcting of sowing terms and forecasting of vegetation termination timing, but nowadays there are no such methods [6].

Quite a promising method for prediction of winter wheat yield could be the determination of time of spring vegetation recovery. This method was proved and suggested by V. D. Medynets [7].

The works by scientists from Poltava describe interesting and valuable information about effect of time of spring vegetation recovery on passage of interphase periods and, thus, changes in crop yield (table 1).

Based on the above data the conclusions were made that ecological effect of time of spring vegetation recovery is indisputable and determines different duration of vegetation period of winter wheat, influences crop productivity level and extent of supply with factors for life during the spring-summer vegetation.

The impact of environmental factors on the yield of winter wheat has been a subject of many scientific works [6–12]. The dependence of the timing of spring vegetation restoration on air temperature was determined previously by a number of scientists [11, 12]. Great effect is also observed in the state of the plants, when they went into winter, winter damage, and the biological characteristics of the variety [13]. The latter is particularly important for wheat breeding, as will be described below. The researchers also noted the impact of such factors as light and moist, however the ambient temperature is the main factor.

Table 1. Dependence of the winter wheat yield and duration of periods from the time of spring vegetation recovery

Rainfall amount during the third decade of August and all September at the time of sowing	Date of spring vegetation recovery	Day duration on the date of spring vegetation recovery	Date of winter wheat heading	Period duration from the date of spring vegetation recovery to heading, days	Total day duration from the date of spring vegetation recovery to heading, hours	Sum of active temperatures (>5°C) from spring vegetation recovery to heading.	Rainfall sum from spring vegetation recovery to heading, mm	Yield, centner/ hectare
101	23.02	10h 24min	22.05	89	1165	690	107	47,2
69	10.03	11h 21min	27.05	77	1086	710	107	44,5
62	22.03	11h 54min	28.05	67	954	713	93	43,2
55	29.03	12h 31min	29.05	61	870	719	105	33,0
36	5.04	12h 44min	06.06	64	936	784	89	23,2
53	16.04	13h 31min	09.06	54	828	717	91	36,4

By analyzing perennial data of variety-testing stations, they established the most favorable meteorological conditions for winter wheat yield more than 50 kg / ha [14–21]. Later, we have found that in the case of Ukraine the formation of wheat yields is considerably influenced by such factors, as rainfall in October, the number of days in the winter with temperatures below minus 17 ° C, the number of days with thawing weather and the number of days in the same period with temperatures above 5° C [22].

According to the research, fluctuations in yield of winter wheat are also affected by moisture reserves in meter soil layer and the number of productive stems per 1 m^2 after winter [23–26]. The recovery time of the spring vegetation can be used not only for prediction of yields or development of technologies of wheat cultivation, but also for the selection process, especially for adaptive selection [27–35].

Research objective

Research objective includes specification of the impact of climatic factors and duration of periods from the time of spring vegetation recovery till heading on winter wheat yield, establishment of major weather factors that influence the formation of yield of cereal winter crops.

Research results

The yield of grain winter crops has a significant variation by years (Tables 2, 3). In 2003, Ukraine received the lowest yield from all years of research. The reason for that was the range of adverse conditions of wintering and spring vegetation recovery (Table 2). That year has been characterized by minimum number of thaws - the national average of 3-4 days (except Crimea and Zakarpattia Oblast, where the total duration of the thaw was 15 and 11 days respectively). The highest yield during mentioned year was obtained in Ivano-Frankivsk - 2.15 t / ha, Lviv - 2.35%, Volyn - 2.60 t / ha and Zakarpattia Oblasts - 2.94 t / ha. The most affected regions included Dnipropetrovsk (0.63 t / ha), Kherson (0.61 t / ha), Kirovohrad (0.72 t / ha), Odessa (0.63 t / ha), Poltava (0.91) and Zaporizhia (0.96 t / ha) Oblasts.

Table 2. Indicators of yield of winter wheat by years
(according to the State Statistics Committee)

Oblasts	Yield, t/ha									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
The AR of Crimea	2,29	2,00	1,51	2,26	2,25	2,50	2,28	2,74	2,32	2,21
Vinnitsa	2,73	3,16	1,39	3,34	3,00	3,12	2,80	4,34	4,08	3,45
Volyn	2,33	3,00	2,60	3,46	2,89	2,33	2,61	3,13	2,81	2,72
Dnipropetrovsk	4,32	3,67	0,63	3,63	3,54	2,91	1,97	3,82	3,00	2,98
Donetsk	3,83	3,21	1,07	3,22	3,14	2,37	2,46	3,64	2,87	3,05
Zhytomyr	2,22	2,75	1,41	2,92	2,41	2,27	2,49	3,47	3,25	2,67
Zakarpattia	2,87	3,05	2,94	4,06	3,29	3,03	3,05	3,07	2,96	2,20
Zaporizhia	3,50	2,81	0,96	3,14	3,03	2,88	2,19	3,54	2,85	2,67
Ivano-Frankivsk	2,02	2,82	2,15	3,17	2,45	2,38	2,61	3,33	3,08	2,66
Kyiv	3,06	3,35	1,64	4,15	3,76	2,83	2,98	4,14	3,87	2,54
Kirovohrad	4,20	3,84	0,72	3,82	3,34	3,03	2,08	3,88	3,11	3,10
Lugansk	3,23	2,58	1,55	2,53	3,18	1,83	2,12	3,82	2,43	2,47
Lviv	2,18	2,76	2,35	3,01	2,46	2,54	2,71	3,28	3,20	2,66
Odessa	3,44	3,11	0,63	3,48	2,41	2,53	1,79	3,33	2,65	2,94
Poltava	3,36	3,66	0,91	3,33	3,36	2,70	2,89	4,36	3,61	2,72
Rivne	2,31	3,23	1,97	3,24	2,58	2,23	2,74	3,29	3,08	3,10
Sumy	2,75	3,15	1,27	3,11	2,52	1,97	2,88	3,92	3,49	2,28
Ternopil	1,86	2,90	1,85	3,14	2,42	2,32	2,74	3,74	3,78	2,70
Kharkiv	3,63	3,73	1,25	3,24	3,70	2,20	2,80	4,63	3,12	2,16
Kherson	3,01	2,41	0,61	2,98	2,45	2,56	1,85	3,28	2,45	2,50
Khmelnytsky	2,08	2,96	1,81	3,11	2,28	1,97	2,64	3,60	3,59	3,09
Cherkasy	3,79	3,56	1,14	3,90	3,76	3,11	2,95	4,74	4,61	3,62
Chernivtsi	1,92	2,90	1,22	2,76	2,50	2,57	3,00	3,32	3,52	2,85
Chernihiv	2,28	2,48	1,46	3,22	2,65	2,26	3,15	3,44	3,46	2,27

Thus, according to the authors, there is a tendency towards shortfall of grain shaft in oblasts that are the most powerful producers of wheat in the country. Moreover, these regions are potential producers of strong wheat grain. At the same time, using this trend, there is an opportunity to pay more attention to Western Forest-Steppe and Zakarpattia zones, as basis for the production of wheat grain in the critical years.

In 2004, weather conditions were much more favorable. Yield depended on the number of thaws with temperature above 5ºC and rainfall in October and

November. In 2005, there was a positive effect of rainfall in September 2004, that is, the most important role was played by moisture reserves accumulated till the autumn vegetation of crops.

Table 3. Indicators of yield of winter barley grain by years
(according to the State Statistics Committee)

Oblasts	Yield, t/ha								
	2001	2002	2003	2004	2005	2006	2007	2008	2009
The AR of Crimea	2,40	1,95	1,63	2,07	1,87	2,27	2,40	2,93	2,45
Vinnitsa	2,77	2,92	1,40	2,91	2,40	2,47	2,24	3,79	3,21
Volyn	2,40	2,35	1,65	3,20	2,58	2,01	2,10	3,20	4,49
Dnipropetrovsk	3,48	2,71	0,80	3,02	2,64	2,70	1,38	3,28	2,85
Donetsk	2,83	2,66	0,45	2,93	2,44	2,00	2,28	3,27	2,59
Zhytomyr	2,90	2,74	1,50	2,65	2,03	1,28	2,09	3,86	3,51
Zakarpattia	2,87	2,87	2,50	3,63	2,89	2,77	2,97	2,85	2,75
Zaporizhia	2,67	2,32	0,47	2,82	1,99	2,30	1,60	3,21	2,66
Ivano-Frankivsk	2,33	2,06	1,78	3,44	2,63	2,18	2,33	2,99	2,91
Kyiv	3,30	2,85	1,70	3,14	2,77	2,35	3,13	4,27	4,21
Kirovohrad	3,51	3,27	0,60	3,08	2,46	2,53	1,70	3,32	3,05
Lugansk	2,59	2,19	1,30	2,20	2,19	1,42	1,82	3,25	2,68
Lviv	2,29	2,22	2,15	2,53	2,54	2,63	2,27	3,14	3,66
Odessa	3,30	2,98	1,11	3,21	2,16	2,28	1,67	3,13	2,62
Poltava	3,08	3,12	0,90	3,11	2,43	2,41	2,53	4,03	4,06
Rivne	2,80	2,40	2,20	2,42	2,35	2,11	3,12	2,77	3,79
Sumy	2,10	2,30	0,00	2,16	1,33	1,09	4,31	2,80	2,83
Ternopil	1,95	2,16	1,16	1,93	2,22	2,01	2,91	4,01	3,58
Kharkiv	3,35	3,40	0,70	3,15	2,79	2,37	2,09	3,75	2,85
Kherson	2,67	1,90	0,50	2,81	2,14	2,10	1,55	3,15	2,50
Khmelnytsky	2,67	2,41	1,79	2,60	2,08	2,02	2,90	3,74	2,78
Cherkasy	3,63	3,11	1,00	3,49	3,06	2,45	2,37	3,96	4,22
Chernivtsi	2,00	2,97	1,39	2,62	2,69	2,26	2,70	3,18	3,02
Chernihiv	2,88	2,19	2,40	1,50	2,08	2,05	3,40	3,37	4,02

The year of 2006 practically did not differ from the previous one in terms of yield, although according to our equations a crucial role was played by precipitation in March. In the year of 2007 the critical factors included the number of days with temperatures above 0^0C and precipitation in February and May.

In 2008, the growing conditions were most favorable. The average yield of grain in Ukraine was 3.66 ... 3.76 t/ha. The highest level was reached in Cherkasy - 4.74, Kharkiv - 4.63, Poltava - 4.36, Vinnytsia - 4.34 and Kyiv Oblasts - 4.14 t/ha. During this generally favorable year the practical factor consisted of the number of thaws with temperatures above 0 º C, which is confirmed by the results of simple and multiple regression analysis.

The average yield around the country in 2009 was 3.22 t/ha. The major role in its formation was played by precipitation in September and December of the previous year; in 2010, the positive role was played by precipitation in November and January.

Data presented in the article were processed by method of correlation analysis. Results have shown that winter wheat yield is greatly influenced by rainfalls in the third decade of August and all September. Correlation ratio between these characteristics is +0,86, the regression equation and graph of dependence are shown on the Fig.1.

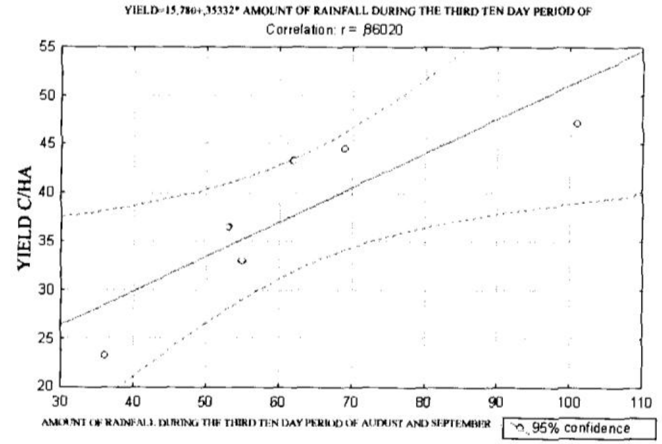

Fig. 1. The graph of dependence between autumn rainfalls and yield

The other important factor is sum of active temperatures during the period from spring vegetation recovery to heading. Effect of this factor is negative – r = -92, regression equation is on the Fig 2.

It is interesting that in long-term studies the influence of rainfall during the period from spring vegetation recovery till heading is practically absent and correlation ratio is insignificant. This, however, does not exclude completely the influence of this factor under the conditions of Ukraine and most likely this fact indicates a great importance of moisture during sowing, wintering conditions and accumulation of moisture in the soil due to winter precipitation.

There is no doubt that for specification it is necessary to analyse the effect of climatic factors during the years combined according to different time of spring vegetation recovery and compare the results. Moreover, the methods of statistical analysis can help find some patterns in relationships between agroclimatic factors, which could be possibly useful for determination of cyclicity of years by time of spring vegetation recovery. These methods could further lead to development of the ways to mitigate the adverse effects by regulating terms of sowing.

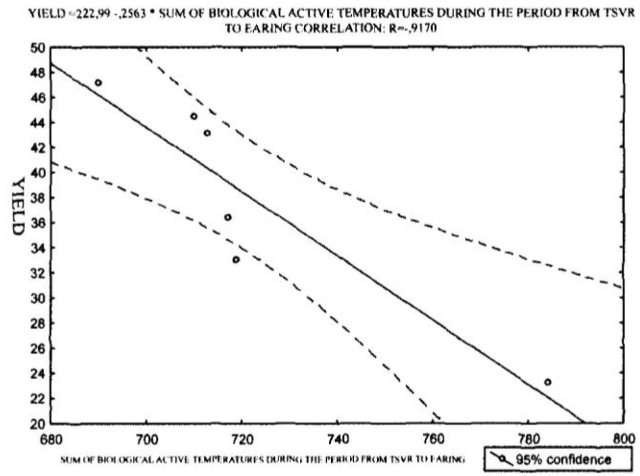

Fig. 2. Yield dependence on sum of biological active temperatures

Though in given data there is no direct connection of yield with the date of spring vegetation recovery, the day duration at the time of spring vegetation recovery, and the duration of period from the date of spring vegetation recovery to heading, it was determined that the time of spring vegetation recovery impacts a number of potentially important factors. Connection of this factor with heading date has practically functional character (r = 0,94). The earlier time of spring vegetation recovery begins, the sooner heading occurs. It indicates not only the plant reaction, but also certain patterns in weather processes. It has been also established that the date of spring vegetation recovery has negative connection with period duration from time of spring vegetation recovery till heading, which is natural, since in the case of early spring vegetation recovery, the duration of spring-summer vegetation period is extended. Furthermore, general day duration from time of spring vegetation recovery to heading in hours has an essential effect on the duration of spring-summer period. The latter indicates a considerable effect of duration and amount of sunshine on yield.

Role of time of spring vegetation recovery for such crops as winter barley requires additional studies, prerequisite for which is the establishment of the main factors affecting the yield of this crop.

The analysis of the influence of weather factors on yields of winter barley during the period of 2001-2009 shows that the greatest influence is made by winter temperatures below minus 15 ° C (r = –0,56), duration of thaws with temperatures above 5 ° C, the duration of thaws above 0 ° C (r = 0,29), and precipitation at the time of sowing (r = 0,17), renewal of spring vegetation (r =0,19), precipitation in April (r = 0,20) and May (r = 0,25).

Despite this supposedly insignificant correlation, the effect is significant at a high statistical level (p <0,01). Thus, based on the results of the regression analysis we can write the following series of equations, which may predict the yield of winter barley.

Analysis of the dependence of the yield of winter barley on meteorological factors by years of research made it possible to come up with a number of equations that worked exclusively in a particular year of research; their use for prediction is effective in case of the similarity of conditions of cultivation years.

Based on results of our studies, the variation of yield and gross yield negatively effects their value - there is a strong inverse correlation between yield and coefficient of its variation ($r = -0{,}81$), and between the gross harvest and the same value – $r = -0{,}69$.

In the forest-steppe subzone of sufficient moisture, major weather factors that limit the yield of winter barley include the number of days with ratures below minus 15 ° C, precipitation in September, which form moisture reserves at the time of sowing, and June precipitation, when grain formation and filling occurs.

Correlation analysis carried out on the basis of 9-year meteorological observations and analysis of productivity for the same period allowed to establish the equations, the results of which are strongly correlated with the actual yield. High values of correlation coefficients are observed in both simple and multiple regression (Table 2).

In the forest-steppe subzone with unstable moisture, for prediction of the yield of winter barley it is also necessary to take into account the duration of the frost period with temperatures below minus 15° C. In this case the correlation coefficient between a simple equation of the predicted yield and the actual yield equals 0,85. Multiple regression equations, which take into account the rain and thaws, have higher correlation coefficients. As in the case of winter wheat, for barley in this subzone the thaw duration with temperatures above 5 ° C is important, as they supposedly deharden the plants even more.

In subzone with low moisture, along with above mentioned influence of subzero temperatures, prognostic factors may also include the precipitation of March and May. The correlation coefficients between the predicted and actual yields are within 0,72 ... 0,81.

In the conditions of Polessye, negative effect on the yield of winter barley is demonstrated by precipitations in January and June. According to the values of the correlation coefficients, the effectiveness of yield prediction for this area may be one of the highest, as the correlation coefficients are within 0,85 ... 0,96.

In the northern steppe subzone there is somewhat stable correlation between the actual yield and the equation containing the number of days with strong (for winter barley) frost (below -15 ° C) as an argument. The correlation coefficient was 0,68. If precipitations occurring during the planting, overwintering and spring vegetation are included in the equation, then the correlation coefficient can reach values of 0,89 ... 0,94.

Thus, the actual yield can be predicted with fairly high reliability.

In the Southern Steppe we were not able to determine a critical impact of sub-zero temperatures, as this zone in this regard is the mildest. The main limiting factor in this zone is the precipitation of spring season. The correlation coefficient between the equation, established by the method of multiple regression, and the actual yield is 0,89.

Table 2 The correlation coefficients between the predicted and actual yield of winter barley in the zones of Ukraine

Equation	r
Forest-steppe zone (sufficient moisture)	
$y = 3{,}04 - 0{,}059 \cdot d_{t<-15}$	0,84
$y = 3{,}28 - 0{,}069 \cdot d_{t<-15} + 0{,}0051 \cdot O_{IX} - 0{,}003 \cdot O_{VI}$	0,91
$y = 3{,}18 - 0{,}0696 \cdot d_{t<-15} + 0{,}0048 \cdot O_{IX} - 0{,}0091 \cdot O_{I} - 0{,}0024 \cdot O_{VI}$	0,95
Forest-steppe zone (unstable moisture)	
$y = 3{,}23 - 0{,}07 \cdot d_{t<-15°C}$	0,85
$y = 2{,}23 - 0{,}077 \cdot d_{t<-15°C} - 0{,}054 \cdot d_{t>5°C} + 0{,}0046 \cdot O_{IX} + 0{,}0146 \cdot O_{XII}$	0,93
$y = 2{,}077 - 0{,}082 \cdot d_{t<-15°C} + 0{,}014 \cdot O_{XII} + 0{,}0077 \cdot O_{XI} + 0{,}0046 \cdot O_{IX} - 0{,}042 \cdot d_{t>5°C}$	0,94
$y = 2{,}89 - 0{,}071 \cdot d_{t<-15°C} + 0{,}012 \cdot O_{XII}$	0,90
Forest-steppe zone (insufficient moisture)	
$y = 3{,}38 - 0{,}08 \cdot d_{t<-15°C}$	0,75
$y = 1{,}67 + 0{,}021 \cdot O_{V}$	0,72
$y = 2{,}24 - 0{,}07 \cdot d_{t<15°C} + 0{,}016 \cdot O_{III}$	0,81
Polessye	
$y = 3{,}15 - 0{,}064 \cdot d_{t<-15°C}$	0,85
$y = 3{,}63 - 0{,}079 \cdot d_{t<-15°C} + 0{,}0038 \cdot O_{IX} - 0{,}0107 \cdot O_{I} - 0{,}0029 \cdot O_{VI}$	0,96
$y = 3{,}68 - 0{,}078 \cdot d_{t<15°C} - 0{,}011 \cdot O_{I} + 0{,}0036 \cdot O_{IX} - 0{,}0027 \cdot O_{VI}$	0,96
Northern Steppe	
$y = 2{,}95 - 0{,}058 \cdot d_{t<15°C}$	0,68
$y = 1{,}733 - 0{,}056 \cdot d_{t<15°C} + 0{,}013 \cdot O_{XII} + 0{,}012 \cdot O_{IV} + 0{,}011 \cdot O_{V}$	0,94
Southern Steppe	
$y = 1{,}15 - d_{t<15°C} + 0{,}013\ O_{III} + 0{,}0079\ O_{V}$	0,89

y – yield, centner per hectare
O - precipitation, mm per month (index - month number)
d - number of days (index - temperature range).

Although the number of days with temperatures below -15 ° C is one of the summands of equation, the coefficient of influence of this factor in the pair correlation was insignificant. However, this does not prove the complete absence of the influence of frost.

Thus, stabilization of yields is the main key to getting large gross grain yield of winter barley.

Conclusions:

1. The formation of winter wheat yield in the conditions of Poltava region is effected by rainfall amount during the third decade period of August and all September, as well as wintering conditions and the amount of moisture reserves formed during winter, and the sum of active temperatures above

5° C during the period from time of spring vegetation recovery to heading.

2. Effect of climatic factors on yield can differ depending on the date of spring vegetation recovery in different years.
3. The date of spring vegetation recovery may contribute to the establishment of natural laws of changes of favourable and unfavourable years. It could, in turn, allow to soften unfavourable effect of weather factors on winter wheat yield using agrotechnic measures.
4. The factors of major influence include winter temperatures below minus 15 ° C (r = -0,56), duration of thaw temperatures above 5 ° C, duration of thaws above 0 ° C (r = 0,29), and precipitation at the time of sowing (r = 0.17), the restoration of the spring vegetation (r = 0,19), precipitations in April (r = 0,20) and May (r = 0,25).

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Wpływ głównych czynników meteorologicznych i czasu odnowy wegetacji wiosennej na rozwój upraw i wydajność plonów zboża ozimego na Ukrainie

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Abstrakt: W artykule przedstawiono wyniki badań wpływu czasu odnowienia wegetacji wiosennej pszenicy ozimej na plony. Ustalono, że główny wpływ mają suma opadów w okresie III dekada sierpnia – wrzesień, warunki zimowania i wysokość rezerw wilgoci powstałych w okresie zimowym, a także sumy aktywnych temperatur powyżej 5 °C w czasie odnowienia wiosennej wegetacji – kłoszenia. Data odnowienia wiosennej wegetacji całkiem może przyczynić się do powstania naturalnych współzależności zmian korzystnych i niekorzystnych lat, co z kolei pozwoli znacznie ograniczyć niekorzystny wpływ czynników pogodowych na plonowanie pszenicy ozimej środkami agrotechnicznymi. W podstrefie wystarczającego nawilżenia przez główne czynniki atmosferyczne, które ograniczają plony jęczmienia ozimego są liczba dni w temperaturach niższych niż -15 °C, opady września tworzące rezerwy wilgoci w czasie siewu oraz opady czerwca, kiedy przebiega formowanie i napełnianie ziarna. W podstrefie niestabilnego nawilżania dla przewidywania plonu jęczmienia ozimego należy również wziąć pod uwagę czas trwania okresu mrozu w temperaturach poniżej minus 15 °C.

Słowa kluczowe: czynniki abiotyczne, agrotechnika, odnowa wegetacji wiosennej.

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