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INFLUENCE OF LAPPED ICE CRUST ON FROST RESISTANCE AND SURVIVABILITY OF WINTER WHEAT IN THE STEPPE OF UKRAINE

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The features of the effect both separately and together of lapped ice crust and low temperatures on winter wheat plants were highlighted. During the research period 2017–2019, the plants of the Mudrist odeska variety, which were damaged by low temperature and ice crust, began to ear by 3–6 days later than undamaged ones.

It was found that under unfavorable conditions of wintering, in particular in plots without snow, the plant density per area unit and productive tillering, as well as grain productivity of the crop, largely depended on the degree of winter hardiness of plants. After growing of winter wheat plants, which was frozen in laboratory conditions (without lapped ice crust) at a temperature of -15 °C, all plants survived, when the temperature dropped to -18 °C, 16.3 % of plants died. A further drop in temperature to -21 °C caused the loss of 81.7 % of plants. Against the background of artificially created lapped ice crust, the tillering nodes of the winter wheat plant were more damaged and, accordingly, the survival rate of plants decreased compared to variants without lapped ice crust, and its indicators were 69.8–92.0 % at a temperature of -15 °C; 12.6–74.5 % at a temperature of -18 °C depending on the thickness of the ice crust. When the cryogenic load increased to -21 °C, winter wheat plants died under the ice crust. During the growing season, in variants of mineral nutrition with a dose of $N_{60}P_{60}K_{60}$, the death of winter wheat shoots compared with the non-fertilized control variant was less by 4.9–23.1 %.

The dynamics of the soluble carbohydrate content in the tillering nodes indicated that the minimum consumption of carbohydrates by plants (30.8 % of autumn reserves) at the spring growth resumption was observed in variants with $N_{60}P_{60}K_{60}$ fertilization. The carbohydrates were intensively consumed by plants in the plots without snow cover under the lapped ice crust, as a result, their amount in the tillering nodes during the winter period decreased on non-fertilized and fertilized variants by 58.5 and 61.2 %, respectively.

***Key words**: winter wheat, frost resistance, mineral fertilizers, ice crust, productivity, survivability.*

Winter wheat (*Triticum aestivum* L.) is a crop with a significant biological yield potential compared to other cereals. One of the main conditions for the realization of the maximum possible productivity of winter plants in the Steppe zone is a successful overwintering [1–3]. During the winter, winter wheat is constantly under the influence of unfavorable meteorological factors – frequent thaws and frosts, sharp temperature drops, which are the cause of plants damage and death, hence the significant losses in agriculture. It should be noted that the general patterns of damage to both aboveground and underground organs of winter wheat plants remain insufficiently studied, despite the constant effect of adverse hydrothermal factors. Special attention needs to be paid to the researches of the influence of low temperatures on the survivability and grain productivity of plants. It is experimentally proved that frost resistance and winter hardiness of winter wheat are determined by the biological properties of varieties and agrotechnological features of cultivation [4, 3].

Cultivation technology and varietal characteristics significantly affect the growth, development, winter hardiness and productivity of winter wheat plants [5, 1]. Research on the implementation feature of the productivity potential allows to forecast the plant states and to adjust spring agricultural measures in order to maximize the realization of grain productivity of winter wheat [6, 3].

Many agricultural scientists have studied the causes of damage and death of winter crops. They proved experimentally that the compacted snow cover does not critically affect the supply of oxygen to plants. However, plants consume a lot of nutrients under a thick layer of snow. Respiration (aeration) is disturbed, the ratio of photosynthesis components changes under conditions when the aboveground part of the plant is completely frozen in ice [7, 8].

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In winter, the greatest danger for winter crops is lapped ice crust, which is formed due to alternating thaws and low temperatures [1]. It melts quickly in the spring, and the transpiration is restored in plants. However, the root system is not fully functional yet. There is depression and sometimes death of plants from physiological drought [9]. Lapped ice crust take a second place after low temperatures on the damage degree of winter plants. The death of winter wheat due to the harmful effects of lapped ice crust was observed in the Northern Steppe in large areas in 1978/79, 1985/86, 1996/97 and 2002/03 growing years, especially with its long occurrence – more than 4 ten-days [1, 10].

In 1935, I. I. Tumanov in his research proved the existence of a direct relationship between frost resistance and resistance to the effects of lapped ice crust. A. I. Zadontsev, V. I. Bondarenko, O. D. Artiukh, V. V. Khmara, I. M. Vasiliev, N. M. Karmanenko, N. G. Tuktarova and other scientists have expanded the understanding of the complex resistance of plants to stress factors of the winter period, and confirmed experimentally the relationship between frost resistance and the damage level of plants due to the action of other adverse hydrothermal factors during this period [1, 11–12]. G. V. Udovenko make a similar conclusions when she established a close correlation relationship between frost resistance and winter hardiness, ie resistance to abiotic factors of winter stress, including ice crust [13].

According to the results of scientific research, a scientific hypothesis about the most important role of the duration of deep dormancy to ensure high resistance to winter stressors was proposed. [14].

It is necessary to know the conditions of its formation and the depth of dormancy of plants at this time to predict the death of winter wheat plants from the harmful effects of lapped ice crust. Thus, with complete melting of snow and thawing of the top layer of soil by 2–3 cm or more, growth of winter wheat recover slowly depending on the winter hardiness of the variety, meanwhile plants lose hardening, breathe intensively and die quickly in the adverse hydrothermal conditions.

Aim. To identify the possibility of predicting damage level and death of winter wheat plants due to the lapped ice crust and low-temperature stress. To determine the application rate of mineral fertilizers to increase the regeneration of winter wheat plants exposed by low temperatures.

Materials and Methods. The research was conducted in the northern subzone of the Steppe on the basis of the State Enterprise Institute of Grain Crops of NAAS during 2017–2019. The soil cover of the experimental plots was full-profile low-humus ordinary chernozem. The humus content in the arable layer was 2.97–3.01 %, gross nitrogen reserves were 0.20 %, mobile phosphorus and exchangeable potassium were 110–153 and 75–127 mg/kg of soil, respectively (according to Chyrykov). The solid row seeding was carried out with a mounted drill SN-16 to a 5–6 cm depth on September 25.

The object of research was a highly productive winter wheat variety Mudrist odeska developed at the Plant Breeding & Genetics Institute, National Center of Seeds and Cultivar Investigation of NAAS; it is of universal use, with a high regenerative potential, frost resistance and winter hardiness of 8–9 points. The field trial was established after winter wheat as the predecessor, on two backgrounds of mineral nutrition: without fertilizers and $N_{60}P_{60}K_{60}$. Nitrogen fertilizers were additionally applied on the fertilized background: N_{30} (end of tillering – beginning of stem elongation stage, locally), N_{30} a.i. kg/ha (heading stage, foliar feeding).

During the greatest cooling, snow was artificially removed in winter wheat crops, and a lapped ice crust of 5–7 cm thickness was created. Control plots were without ice crust. The plot area was 2 m^2, replication was four times. The temperature at the tillering node depth was monitored with minimum thermometers. Additionally, the reaction of plants to the artificially created ice crust with 5, 7 and 11 cm thickness was studied in the laboratory, in vegetation vessels. Then the monoliths were frozen at a temperature of –15… –18… –21 ^{o}C with exposure for 24 hours. After that, winter wheat plants were grown at a temperature of 18 ... 24 ^{o}C and 16-hours illumination with fluorescent lamps with a light intensity of 12,000 lux. We used generally accepted methods and recommendations during research [3, 15–17].

Weather conditions over the research years were typical for the Steppe zone, and they differed in both temperature and precipitation during growth season of winter wheat. Special mention should be made of the hydrothermal conditions of the periods of sharp cooling in 2017–2019. Thus, the minimum air temperature in the I – II ten-days of January 2017 decreased to –16… –20 ^{o}C, the soil surface cooled to –19… –24 ^{o}C. In the third ten-days of January the minimum air temperature was –21… –25 ^{o}C at night. In the second ten-days of January 2018, at night, its indicators were –13… –15 ^{o}C, and on the soil surface – –18… –19 ^{o} C. In the third ten-days of January, there was also frosty weather with a decrease in temperature to –21 ^{o}C. In 2019, in the first ten-days of January at night the air temperature decreased to –8… –14 ^{o}C, the soil surface cooled to –11… –16 ^{o}C, and in the second ten-days – to –11…–19 and –15… –23 °C, respectively. In the third ten-days of January the air temperature decreased to –20… –24 °C. Frosty weather was also observed in February 2019, but the soil temperature at the tillering node depth did not reach critical values, even in the variants without snow; at the end of the first ten-days of February the minimum air temperature was –2 ...– 4 °C, and the on soil surface its indicators fluctuated within –2… –6 ^{o}C. In general, the weather conditions in the years of research were contrasting, periods of sharp cooling alternated with periods of warming, but the period of continuous occurrence of lapped ice crust did not exceed two ten-days.

Results. Observations showed that under the ground ice crust, the minimum soil temperature at the tillering node depth was significantly lower than in the control (Table 1). During the sharp cooling, the temperature difference between the trial variants increased, which is explained by the basic Fourier's law of thermal conduction:

$$q= - k \text{ grad } T, \text{ where}$$

q – the vector of local heat flux density, W/m^2; k – the materials conductivity, W/(m·K); gradT – the temperature gradient, K/m.

When the temperature decreases, the thermal conductivity of the ice crust accordingly increases. For some days (January 15–23, 2019), the minimum temperature at the tillering node depth in the variants with lapped ice crust reached –16.2… –18.5 °C, while in the control (without snow) – –13, 4… –14.3 °C. The survivability of winter plants, under low- temperature stress and the lapped ice crust was 58.2–64.5 %; instead, in the control variants, its indicators were higher and ranged from 74 to 86 %.

1. Change of soil temperature on plots without snow during periods of sharp cooling at the tillering node depth of winter wheat plants (2019)

Variant	Soil temperature at the tillering node depth, °C					
	January 7	January 15	January 23	February 8	February 16	February 23
Without ice crust (control)	-11.0	-14.3	-13.4	-3.1	-2.9	-6.3
Lapped ice crust	-13.4	-18.5	-16.2	-4.0	-3.8	-8.1

Thus, cryogenic loads and partial deterioration of aeration in plants frozen in ice negatively affected the metabolic processes that resulted to decrease the regenerative potential of the tillering node cells. In the field trials without snow, it was observed that the upper soil layer freeze through, and the lapped ice crust intensified the negative effects of low-temperature stress and caused the death of aboveground part, damage to the tillering node and root rupture of plants.

At the time of harvest, the spareness was increased due to the spring-summer extinction of some plants weakened and damaged during the overwintering. Given that the implementation of anti-stress properties of winter wheat requires significant energy costs, it is important to provide mineral nutrients, which due to their physiological action have anti-stress effect and positive impact on plant survivability and productivity. In the variants with the application of $N_{60}P_{60}K_{60}$, the shoots death of winter plants during the growth season was less compared to the control variant (Table 2).

2. Dynamics on death of damaged plant shoots (%) due to low temperatures and lapped ice crust during the spring-summer growing season (average for 2017–2019)

Variant	Fertilizers	Phenological phase		
		stem elongation	heading	dough maturity
Without ice crust (control)	without fertilizers	8.4	38.1	44.5
	$N_{60}P_{60}K_{60}$	6.8	35.7	39.3
Lapped ice crust	without fertilizers	14.2	57.1	66.2
	$N_{60}P_{60}K_{60}$	10.5	54.3	61.7

The low-temperature stress causes damage of tillering node and created the greatest danger to plants. In the future, there is a suppression of the process of growing vegetative mass, a decrease of the total and productive tillering, a grain content and weight per the ear in such plants. It should be noted that the plants of Mudrist odeska variety, which were exposed to the harmful effects of frost and ice crust, began to ear 3–6 days later compared to intact plants. Under adverse overwintering in plots without snow cover, the level of winter hardiness significantly affected the plant density per unit area and productive tillering, which determined the productivity of damaged plants; it decreased from 12.3 to 53.4 %.

The laboratory studies were conducted to further study the complex negative influence of low-temperature stress-factor on the viability of winter wheat plants, where under controlled conditions they were frozen at different temperatures. So, plants were grown after freezing at a temperature of –15 °C; all of them survived in variants without the lapped ice crust, when temperature decreased to –18 °C 16.3 % of them died. Further decrease in temperature (down to -21 °C) led to the death of 81.7 % of plants. The tillering nodes were more severely damaged under artificially created lapped ice crust and, accordingly, the survivability of winter wheat plants decreased in contrast with variant without ice crust: the plant survivability was 69.8–92.0 % at a freezing temperature –15 °C; it was 12.6–74.5 % at –18 °C and depended on the ice crust thickness. When the cryogenic load increased to –21 °C, all plants under the ice crust died (Table 3).

3. Influence of low temperatures and ice crust on survivability of winter wheat plants (%), exposure – 24 hours

Temperature of freezing, °C	Plant survivability, %			
	without ice crust	ice crust thickness, cm		
		5	7	11
Without freezing	100	100	100	100
-15	100	92.0	82.1	59.8
-18	91.7	74.5	47.1	12.6
-21	18.3	0	0	0

The dynamics of soluble carbohydrate content in the tillering nodes indicates that at spring growth resumption of winter wheat plants there was a significant decrease of their content due to adverse weather conditions, especially low-temperature stress factor. The minimum consumption of carbohydrates was observed in fertilized variants and amounted to 30.8 % of autumn reserves. In plots without snow cover and covered with lapped ice crust, carbohydrates were intensively consumed by plants, as a result, their amount in the tillering nodes during the winter in unfertilized and fertilized variants decreased by 58.5 and 61.2 %, respectively (Table 4).

4. Dynamics of soluble carbohydrate content in tillering nodes of winter wheat plants, % of dry matter (average for 2017–2019)

Variant	Fertilizers	Content of soluble carbohydrates, %		
		monosaccharides	disaccharides	total sugar
growth arrest				
Control	without fertilizers	11.2	23.1	34.3
	$N_{60}P_{60}K_{60}$	13.7	28.2	41.9
growth resumption				
Without ice crust (control)	without fertilizers	7.2	15.6	22.8
	$N_{60}P_{60}K_{60}$	9.7	19.3	29.0
Lapped ice crust	without fertilizers	4.1	9.2	13.3
	$N_{60}P_{60}K_{60}$	6.5	10.9	17.4

Conclusions. We can make the following conclusion based on the above data: in the case of a short period of lapped ice crust occurrence (less than 2 ten-days), there was a significant cryogenic load on winter wheat plants, which resulted in death of aboveground vegetative mass, damage to tillering nodes, root rupture and decrease in the regenerative potential of the tillering node cells.

Thus, even under a short occurrence period at abnormally low temperatures, lapped ice crust due to higher thermal conductivity causes rapid penetration of heat flow through the ice surface and saturated with water and frozen upper 0–10 cm layer of soil, as a result – reduction of tillering node temperature to the critical value, which causes damage and death of plants in severe snowless winter.

Spring-summer extinction of some weakened and damaged plants during the overwintering and grain yield losses partially compensated by the application of mineral fertilizers, which cause anti-stress effect and have a positive effect on plant survivability and productivity. The death of winter wheat shoots on the fertilized background of $N_{60}P_{60}K_{60}$ was decreased during the growing season by 4.9–23.1 % compared to the unfertilized variant.

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