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Influence of structural density and soil moisture on the productivity of intensive and semi-intensive spring barley varieties

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Goal. To determine the influence of agrophysical parameters of arable soil layer on the productivity of spring barley varieties of different types of intensity under conditions of application of mineral fertilizers on the example of typical deep low humus deep-boiling heavy loam on loess-like loam chernozem of the Left Bank part of Forest-steppe of Ukraine. **Methods.** Laboratory-analytical, laboratory-model, field (small-area), mathematical-statistical, computational. **Results.** The improvement of conditions of germination, development, and increase of biological mass of cultivars of the studied culture at soil density and humidity at the level of 1.2 g/cm3 and 80% of the lowest moisture content (LMC) in comparison with compacted soil is established. The optimal values of structure density and soil moisture are determined, which ensure the maximum biomass of intensive variety of spring barley Vzirets: 1.2 g/cm3 and 100% of LMC (at the application of 90 kg/ha of the active substance (a.s.) of nitrogen, phosphorus and potassium fertilizers); semi-intensive variety Zdobutok: 1.2 g/cm3 and 80% of LMC (at the application of 45 kg/ha of nitrogen and phosphorus fertilizers, and 90 kg/ha of potassium fertilizers). In the course of field research, a decrease in the use of nutrients from the soil was revealed: nitrogen by 4.0% — for intensive and 2.0% — for semi-intensive varieties; phosphorus — by 3.4 and 4.7%; potassium — by 10.7 and 6.3%, respectively, at a high (1.4 g/cm3) level of compaction compared to its low (1.0 g/cm3) level. Under the same conditions, a decrease in the yield of spring barley grain was revealed: intensive variety — by 25, semi-intensive — by 22%. **Conclusions.** According to the results of experimental studies, the complex influence of soil moisture and compaction levels was revealed and their optimal parameters were established for growing intensive and semi-intensive varieties of spring barley, which achieved their maximum yield in soil fertilization.

Key words: *mineral fertilizers, typical heavy loam chernozem, biomass, nutrients, spring barley.*
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Analysis of recent research and publications. Spring barley (*Hordeum vulgare L.*) is one of the most widespread grain cultures in the world. Ukraine is one of the largest producers of barley in the world (9.9 million tons in 2016-2017). The sown area of this crop is decreasing (from 5.8 million hectares in 2003 to 2.9 million hectares in 2017), and barley grain yield has increased from 2.0 to 3.43 t / ha over the last 7 years. If spring barley is grown under favorable climatic conditions, the level of grain yield can reach 9.0 - 10.0 t/ha. Ukraine ranks 3rd in the world in terms of exports of this crop (5.3 million tons in 2016 - 2017), and local using of barley in our country is 3.9 million tons [1].

Typical chernozem is one of the suitable soils for growing spring barley. However, the negative anthropogenic impact on the agrophysical properties of this soil is the cause for finding ways to optimize them. As noted by V.V. Medvedev, chernozem soils of loamy texture are more favorable for compaction than soils of other genesis and texture [2]. The cause for this sign is that these soils have a low bulk density before tillage, a well-defined but mechanically weak structure, significant interaggregate porosity and humidity (especially in the spring), nearly to physical maturity. The result of overcompaction of chernozem soils is a decrease power and productivity of root systems of plants, weakening adaptation of plants to deficit of moisture, a sharp deterioration in the quality of the arable layer after its tillage [3, 4].

Many years of research by prominent scientists has revealed the optimal bulk density of soil for grain crop, which ranges from 1.1 to 1.3 g/cm^3. Exceeding this indicator leads to deterioration of moisture accumulation in arable and root-containing layers and its use by plants from soil, negatively affects further growth and development of plants, decrease in absorption by plants of mineral nutrients from soil and fertilizers as a result of deterioration of parameters of root system of plants, reduction of pore space in compacted soil, which slows down the mobility of the soil solution [5 - 8].

Modern land users prefer modern sorts of spring barley of different types of intensity, which are grown in the forest-steppe of Ukraine. Therefore, there is a need for additional research by related to the establishment of optimal agrophysical parameters (bulk density and humidity) of the arable layer of chernozem typical for the cultivation of intensive and semi-intensive sorts of barley. It also requires a more detailed research of the effect of levels of soil compaction on the absorption and assimilation of nutrients by plants of different of intensities sorts under conditions by fertilizer application.

The purpose of research - to determine the influence of agrophysical parameters of arable soil layer on productivity sorts of spring barley of different type of intensity under conditions by the application mineral fertilizers on the chernozem typical deep low-humic deep-boiling heavy-loamy on loess on Left-bank Forest-steppe of Ukraine.

Materials and methods of research. The research were carried during 2015 - 2017 in the village Novyi Korotych, Kharkiv district, Kharkiv region within the State Enterprise "Experimental Farm "Grakivske" of NSC" ISSAR named after O.N. Sokolovsky». The soil of the experimental plot - chernozem typical deep low-humic deep-boiling heavy-loamy on loess with content in the arable layer: humus (according to DSTU 4289: 2004) - 3.6 %; of total nitrogen (according to DSTU 4729: 2007) - 12.8 mg/kg of soil; of mobile phosphorus and potassium according to Chirikov (according to DSTU 4115: 2002) - 219.3 and 225.9 mg/kg of soil, respectively.

The basic agrophysical indicators of the arable layer of the soil (levels of soil bulk density and soil moisture) were modeled by laying and conducting a series of laboratory-model and temporary field small-plot experiments. In laboratory model experiments we studied the factors of soil compaction (1.0; 1.2; 1.4 g/cm^3), soil moisture (60; 80 and 100 % of field capacity), fertilization conditions (without fertilizers; $N_{45}P_{45}K_{45}$; $N_{90}P_{90}K_{90}$). Such doses of fertilizers were selected during the analysis of the literature [9, 10], which shows that in the Kharkiv region the largest increase in yield of modern sorts of spring barley was obtained by the application $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$. It was also found that to obtain high yields on fertile soils you need to application $N_{45\text{-}60}P_{45\text{-}60}K_{45\text{-}60}$, and high-yielding (intensive), sensitive to fertilizers and resistant to lodging sorts produce maximum yields with increasing doses of fertilizers to $N_{90}P_{90}K_{90}$ - $N_{120}P_{90}K_{90}$.

Different combinations of these factors were researched in laboratory containers. Their volume was 1.4 dm^3. Filling the containers with soil, calculating the weight of water for irrigation, sowing of plants was carried out according to the method of F.O. Yudin [11]. Laboratory-model experiments were carried in the 3-fold repetition. The length of the experiments - to the 4th leaf in the plants. Types of mineral fertilizers that studied: nitrogen (experiment № 1) - ammonium nitrate (34% N), phosphorus (experiment № 2) - simple superphosphate (20% P2O5), potassium (experiment № 3) - potassium salt (40% K2O). The experimental crop is intensive (Vzirets) and semi-intensive (Zdobytok) sorts of spring barley.

In field small-plot experiments, the study factors were soil bulk density and fertilizer conditions (the levels of the studied factors are similar to laboratory model experiments). Repetition was three times, the placement of variants is systematic. The size of each plot was 1 x 1 m. Mineral fertilizers are similar to those used in laboratory model experiments. Plowing on the plot was carried out to a depth of 25 - 30 cm before laying the experiment in autumn 2015. Fertilizers were applied before sowing to a depth of 10 cm. The set parameters of soil bulk density were modeled in a layer of 0 - 25 cm before sowing by hand using a metal compactor by ramming.

The research area is located in the Left Bank part of the Forest-Steppe of Ukraine with a temperate-continental climate. By the years of research, the average temperature during the growing season of spring barley ranged from + 17.7 °C (2015); + 17.6 °C (2016) to + 16.1 °C (2017) with average long-term indicators + 16.9 °C. The amount of precipitation during the growing season was - respectively 368.6; 512.7 and 211.2 mm at the average long-term norm of 235 mm. In general, the conditions of the growing season in 2015 were characterized as sufficiently wet (hydrothermal coefficient = 1.6), in 2016 - as excessively wet (hydrothermal coefficient = 2.4), in 2017 - as arid (hydrothermal coefficient = 1.3).

The results of research and their discussion. As a result of modeling the levels of soil bulk density and humidity, it was found that a high level of soil compaction (1.4 g/cm^3) in combination with a low level of humidity (60 % of field capacity) leads to slowing down and uneven germination of spring barley, reducing the length and diameter of the roots and reducing the overall biological mass of the crop. It was fixed a decrease the diameter of the roots from 0.45 - 0.50 to 0.2 - 0.3 mm and a decrease their length from 10 - 12 to 7 - 6 cm with an increase soil compaction from 1.0 to 1.4 g cm^3 , which was observed at low humidity of soil. Under the same conditions, a tendency to decrease the productivity of the root system of plants of the studied sorts of spring barley was established.

As a result of research, the optimal ratio of moisture and density parameters of typical heavy loam chernozem was determined, which provided the formation of the maximum biomass of cultivated sorts of spring barley. It is statistically proven that the high level of humidity and average level of soil density (100% of field capacity and 1.2 g/cm^3) promotes to the formation of the maximum biological mass of intensive sorts under conditions by application high doses of mineral fertilizers - N_{90}, P_{90} and K_{90}, and average level of humidity and density of soil (80 % of field capacity and 1.2 g/cm^3) - in semi-intensive sorts under conditions by application of average doses of nitrogen (N_{45}), phosphorus fertilizer (P_{45}) and high dose of potassium fertilizer (K_{90}). The relationship between the levels of humidity and density of the arable layer of typical heavy loam chernozem and the productivity of spring barley sorts is confirmed by high correlation coefficients (for intensive variety r = 0.77 - 0.96, for semi-intensive variety r = 0.83 - 0.96).

According to the results of field experiments, it was found that growing plants by the average (1.2 g / cm3) level of soil density and by the application mineral fertilizers, regardless of their dose, increased the height of spring barley, the number of productive stems, and coefficient of tillering (table).

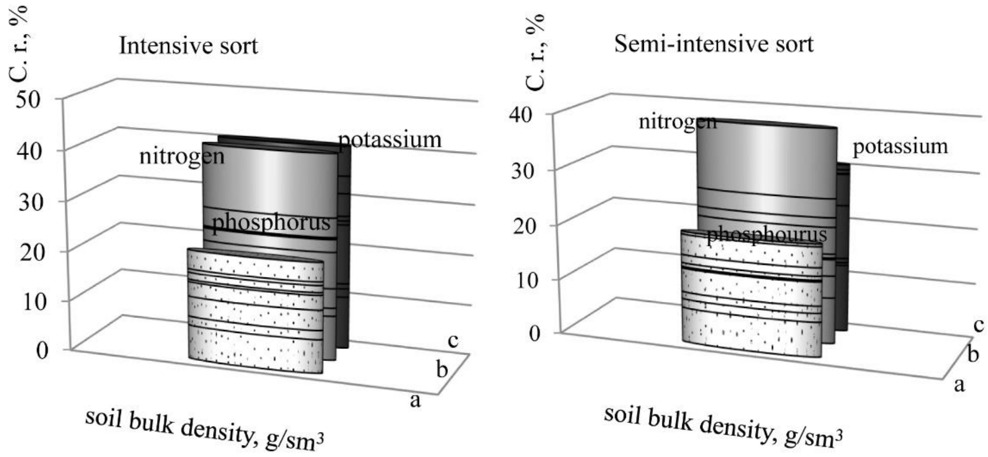
Influence of soil bulk density on biometric indicators and yield of spring barley sorts under the conditions by application of fertilizer (average for 2016-2017)

Soil bulk density, g/sm^3 (B)	Plant height, cm		Number of productive stems, pcs / m^2		Coefficient of tillering		Yield, c/ha	
	Vzirets (A)	Zdobutok (A)	Vzirets (A)	Zdobutok (A)	Vzirets (A)	Zdobutok (A)	Vzirets (A)	Zdobutok (A)
without fertilizers (C)								
1,0	78	95	615	512	1,36	1,14	25,5	31,3
1,2	81	91	612	528	1,36	1,18	31,8	33,0
1,4	74	82	603	476	1,35	1,06	23,8	25,8
$N_{45}P_{45}K_{45}$ (C)								
1,0	83	99	730	634	1,63	1,41	43,3	41,5
1,2	92	108	806	660	1,79	1,47	45,5	46,3
1,4	81	99	723	615	1,61	1,37	38,3	38,3
$N_{90}P_{90}K_{90}$ (C)								
1,0	84	101	833	679	1,85	1,51	42,0	46,8
1,2	89	106	839	723	1,87	1,61	47,0	50,5
1,4	79	98	794	640	1,77	1,43	40,0	43,5
HIP_{05} factor A	2,3		1,22		1,48		2,27	
B	2,8		1,5		1,8		2,75	
C	2,8		1,5		1,8		2,75	
interaction AB	3,9		2,1		2,5		2,8	
AC	3,9		2,1		2,5		2,8	
BC	4,8		2,5		3,1		4,7	
ABC	6,9		3,6		4,4		6,7	

The smallest number of productive stems on 1 m^2 (603 and 476 pcs/m^2 for intensive and semi-intensive barley sorts) was formed on compacted variants. The largest number of productive stems (839 and 723 pcs/m^2 in intensive and semi-intensive sorts) was formed by the average level of soil density (1.2 g/cm^3) under conditions of soil fertilization ($N_{90}P_{90}K_{90}$). The coefficient of tillering of intensive sort ranged from 1.35 to 1.87, semi-intensive sort - in the range of 1.06 - 1.61, reaching the maximum value at the average level of soil compaction.

The highest yields in the experiment: 47 c/ha for intensive sort and 50.5 c/ha for semi-intensive sort were obtained at the average (1.2 g/cm^3) level of soil bulk density under the conditions of application $N_{90}P_{90}K_{90}$, which is 1.5 and 4 c/ha greater than by application the average dose of fertilizer ($N_{45}P_{45}K_{45}$).

The influence of soil compaction on the absorption of nutrients was estimated by the value of the coefficients of recovery of nutrition from the soil (C.r., %). There was found a slowdown the absorption of nutrients by plants at a high (1.4 g/cm^3) level of soil compaction, which affected the reduction of the values of their recovery from the soil: nitrogen - by 4.0 % for intensive and 2.0 % for semi-intensive sorts; phosphorus - by 3.4 and 4.7 %; potassium - by 10.7 and 6.3 %, respectively, compared with low (1.0 g/cm^3) level of soil compaction (Figure).



a - without fertilizers; b - $N_{45}P_{45}K_{45}$; c - $N_{90}P_{90}K_{90}$.

Influence of soil compaction on the coefficients of recovery of nutrition from the soil by spring barley under the conditions of its fertilization

It was found that average (1.2 g / cm3) and low (1.0 g / cm3) levels of bulk density contributed to the maximum recovery of nutrients from the soil by spring barley: C.r. of nitrogen was 20.9 and 19.9 % for intensive and semi-intensive sorts; C.r. of phosphorus - 9.1 and 9.3 % and C.r. of potassium - 22.1 and 17.2 %, respectively.

It was found that under the conditions by application $N_{90}P_{90}K_{90}$ the C.r. of nutrients was doubled in comparison with the variants without fertilizers, but it did not differ much from the variants by application of $N_{45}P_{45}K_{45}$. Therefore, by reducing the dose of mineral fertilizers from 90 to 45 kg/ha of active substance it is possible to improve the conditions of mineral nutrition and achieve maximum absorption of nutrients by spring barley plants by pre-sowing regulation of soil bulk density (for example, using a rotary cultivator TLSM-5 (soil tillage loosening and separating machine)).

Calculations of economic efficiency of optimization of soil density for growing sorts of spring barley were carried out on conditional additional profit, determined by the difference between additional profit and additional production costs, which included costs for seeds, fertilizers and their application, harvesting. It was found that the creation of the bulk density of typical chernozem at the level of 1.2 g/cm^3 during the sowing of spring barley can provide a maximum profit, which an average for researcher period was 119.9 USD/ha (for intensive sort) and 79.8 USD/ha (for semi-intensive sort) by application of $N_{45}P_{45}K_{45}$. Growing spring barley by application of $N_{90}P_{90}K_{90}$ is economically unjustified, as the profit from increasing yields by increasing fertilizer doses does not exceed the cost of purchasing and applying them.

Conclusions

According to the results of experimental researches, it was defined the complex influence of levels of soil moisture and compaction and their optimal parameters for growing intensive and semi-intensive sorts of spring barley were established, at which their maximum yield was achieved under conditions of soil fertilization. It was achieved an increase in the intensity of assimilation of basic nutrients by plants of spring barley from the soil by regulating soil bulk density and reducing the doses of mineral fertilizers (from $N_{90}P_{90}K_{90}$ to $N_{45}P_{45}K_{45}$). This makes it possible to reduce the man-made burden on the environment, saves resources and reduces the cost of agricultural production.

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