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METHODS OF CROP ADAPTATION TO UNFAVORABLE AGROPHYSICAL PARAMETERS OF THE ARABLE SOIL LAYER

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Abstract

Under current conditions of climate change and intensive anthropogenic pressure on soils, it is extremely important for the agro-industrial complex of Ukraine to increase the productivity of crops. In recent years, there has been an increase in air temperature, unstable soil moisture in important phases of plant growth, reduced water permeability and moisture availability to plants, compaction, destruction of agronomically valuable structure, which necessitated finding ways aimed at strengthening the biological capabilities of crops and their adaptation to unfavorable soil and physical conditions. The results of laboratory and field research to test different ways of adapting crops to unfavorable agrophysical parameters of the arable soil layer, based on enhancing the growth of the root system and improving its physiological activity through: agrotechnical activities, selection of adaptive varieties of different intensity types and application of mineral fertilizers. It is proved that the use of the developed methods improves the germination, growth and development of crops, increases the productivity of their root system and promotes sustainable yields of crops.

***Key words**: agrophysical parameters, arable layer, crops, methods of adaptation.*

INTRODUCTION

The main issue of the agro-industrial complex of Ukraine is to ensure maximum productivity of crops. This issue becomes especially relevant in the current conditions of climate change and intensive anthropogenic pressure on soils.

Increasing the intensification of production and use of heavy tillage equipment leads to increasing manifestations of physical degradation, which is expressed in the deterioration of physical and physical-mechanical properties of the soil. Scientists emphasize that in Ukraine the area of overcompacted soils is 17 million hectares, disaggregated (with deteriorated structural units) - 14 million hectares (33.7-39 % of the total area of agricultural land), sprayed - 14 million hectares, soils with lump formation - 4 million hectares, soils with crusting and overcrusting - 15.8 million hectares (Baliuk et al., 2017; Kravchenko, 2019; Medvedev et al., 2020; Vakhniak & Kozhevnikova, 2014).

According to expert estimates, the potential annual losses from soil overcompaction in Ukraine could reach about 1.6 billion euros, and potential crop losses will cost about 1 billion euros (Zabrodskyi et al., 2021).

Soil compaction leads to deterioration of soil agrophysical, biological and agrochemical properties, water, air and heat regimes, reduced germination of agricultural seeds, germination and development of their root system and as a result - to a significant (up to 50%) reduction in productivity compared to uncompacted areas. Compacted soil complicates the penetration of roots into the lower horizons and limits the ability of plants to use nutrients from soil and fertilizers (Plisko et al., 2021).

Following the research by Medvedev and co-authors (2004), the movement of moisture inside the soil also depends on the density of its structure. Any changes in the density of the soil profile delay the flow of moisture.

According to the literature, the optimal water regime in the soil is in the range of 65-75% of the lowest moisture content (Medvedev et al., 2011). However, in recent years there has been climate change, manifested in uneven distribution of precipitation over the years, more frequent droughts and sharp fluctuations in air temperature, and as a result we have unstable soil moisture in important phases of plant growth. In accordance with scientific data (Medvedev, 2015; Kornus & Lynok, 2017), over the last decade the annual average air temperature has increased by (2-3)ºC, and the amount of precipitation over the past 25 years has decreased by 25%. Weather conditions are changing dynamically, their alternation in some years is becoming less predictable, which leads to an unstable level of crop productivity.

There are many data in the scientific literature on the influence of agrophysical properties on the growth and development of crops (Gangur 2018; Mokrikov, 2019, Medvedev, 2015; Szatanik-Kloca et al., 2018). Ways of regulating agrophysical properties of soil are also widely studied, but the issue of adaptation of crops to negative agrophysical properties of soil due to climate change is insufficiently studied and remains relevant to date.

It is well known that any extreme conditions have a much smaller negative impact on plant productivity if they have a well-developed, deep root system. Plants with a deep root system not only better adapt to lack of moisture, high and low temperatures, but also are able to maximize the use of nutrients from the underarable layer for crop formation (Bondarenko & Tkalich, 1976). The development of the root system of plants, and especially its root hairs, plays an important role in the absorption of nutrients and interaction with microorganisms in the soil (Shibata & Sugimoto, 2019).

Thus, research by Tyutyunnyk and co-authors (2021) found that the use of growth regulator in seed treatment and subsequent foliar fertilization of crops on the background of the main mineral fertilizer $N_{16}P_{66}$ promotes adaptation of winter wheat to autumn moisture deficit and allows obtaining additional yield increase hundreds kg/ha (7%). The use of this stimulant-adaptogen led to a decrease in plant height by 2.5% (2.2 cm), increasing the share of straw in the structure of the crop.

Under modern conditions of deterioration of agrophysical parameters of the arable soil layer, the selection of adaptive varieties of different types of intensity can also be an effective way to influence the level and stability of crop yields (Demidov & Gudzenko, 2016; Molotskyy et al., 2006). Research showed that varietal characteristics of crops play an important role in the choice of technology and soil growing conditions. Selection of varieties with different degrees of intensity can significantly reduce the impact of adverse growing conditions on the level of yield due to the different adaptation of a particular variety to certain soil parameters (Bakhmat et al., 2021; Gudz et al., 2014; Kolesnichenko et al., 2012; Kucherak & Berdnikova, 2021).

Highly adaptive and intensive varieties are able to form fairly high yields under favorable growing conditions, but slightly reduce the yield and its quality in adverse. This is especially true in the context of global climate change and frequent non-compliance by growers with recommended cultivation technologies.

It is known that with increasing intensity of varieties there is a natural decrease in their adaptive potential. The potential of plants of new varieties, even under optimal biotic and abiotic factors, is realized only by 50-60% (Popov & Ermantraut, 2013).

Varieties of semi-intensive type are characterized by increased resistance to both short-term and prolonged droughts or high humidity, which occur during one of the periods of any phenophase. These varieties use natural soil resources and mineral fertilizers in limited doses more efficiently than extensive and intensive varieties. Their disadvantage is the lower level of productivity than the varieties of intensive type, due to the tendency to lodging.

The above highlights the need to develop effective ways to adapt crops to the negative agrophysical parameters of the root layer of the soil, which will achieve maximum productivity and sustainable yields of crops.

Thus, the aim of the research was to investigate the ways of adaptation of agricultural crops to unfavorable agrophysical parameters of the arable soil layer.

MATERIALS AND METHODS

Experimental investigations were carried out in the Soil Geoecophysics Laboratory named after Academician of NAAS V.V. Medvedev of the National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" in many factorial laboratory and field experiment.

The study was conducted on typical heavy-loamy chernozem.

A series of laboratory and model experiments were conducted to investigate the methods of adaptation of corn and spring barley to soil overcompaction. The methods of adaptation were the application of growth stimulants, selection of adaptive varieties, soil moisture levels.

The experiments were performed in a light cabinet in vegetation plots with a volume of 1.5 dm^3 in triplicate. The appropriate volume of soil was filled into the plot and an overcompacted subseed layer with a density of > 1.3 g/cm^3 was simulated artificially (with a wooden seal) by pounding. Seeds of the studied crops were sown on this layer and covered with loose soil. Plants were watered through a glass tube so that water came from below. The irrigation rate for the given parameters of soil moisture was calculated according to the method (Agrochemical research in experiments on soil cultivation and fertilization: guidelines, 1977). Duration of experiments - until the appearance of the 4^{th} leaf by plants. The morphological parameters of the root system were determined - diameter and length; the coefficient of root productivity (as the ratio of dry mass of aboveground plant organs on the plot to dry root mass) and biological yield of cultivated crops as the sum of raw biological (aboveground and root) mass of plants was calculated (Stankov, 1964).

In laboratory experiment № 1 the effect of inoculation of corn seeds (variety - hybrid Monolith MV) with growth stimulator "Vympel" on germination, growth and development of plants under the conditions of its cultivation on compacted soils was studied.

Scheme of laboratory experiment №1:

Control: without growth stimulants, soil density > 1.3 g/cm^3;

Variant 1: soil density > 1.3 g/cm^3, Vympel (400 g/t);

Variant 2: soil density > 1.3 g/cm^3, Vympel (500 g/t);

Variant 3: soil density > 1.3 g/cm^3, Vympel (600 g/t).

In the experiment we maintained the optimal level of humidity - at 80% of the field soil water capacity (s.w.c.).

In the laboratory experiment № 2, the influence of levels of soil moisture and variety of spring barley on germination, growth and development of plants under conditions of overcompaction was studied. The studied varieties of spring barley - (intensive variety Vzirets and semi-intensive variety Zdobutok).

The scheme of the laboratory experiment provided the following options:

Control: soil density 1.2 g/cm^3, moisture content 80% of s.w.c.;

Variant 1: soil density > 1.3 g/cm^3, moisture content 60% of s.w.c.;

Variant 2: soil density > 1.3 g/cm^3, moisture content 80% of s.w.c.;

Variant 3: soil density > 1.3 g/cm^3, moisture content 100% of s.w.c.

Under the conditions of temporary field small-scale experiment, adaptive varieties of barley and pre-sowing application of complex mineral fertilizers of spring in the conditions of soil overcompaction were studied. Replication - three times, placement of options - systematic. Area of plots - 1 m^2. Soil overcompaction was simulated in a layer of 0-25 cm before sowing by hand using a metal compactor by pounding.

The scheme of the experiment provided the following options:

Control: without fertilizer, soil density 1.2 g/cm^3;

Variant 1: soil density > 1.3 g/cm^3, without fertilizer;

Variant 2: soil density > 1.3 g/cm^3, 45 kg/ha of active substance (a. s.) NPK;

Variant 3: soil density > 1.3 g/cm^3, 90 kg/ha of a. s. NPK.

Applied mineral fertilizers: ammonium nitrate, simple superphosphate and potassium salt. The studied varieties of spring barley are similar to those used in the laboratory experiment № 2.

In the field experiment, phenological observations of plant growth and development were made: seedling dates were recorded, plant height, number of productive stems (with ears) were determined, and crop accounting was performed. The tillering coefficient was also calculated (as a fraction of the division of the total number of shoots with ears by the total number of plants from one plot).

Mathematical and statistical processing of research results was performed by the method of analysis of variance using software packages Statistica 10.0 and Microsoft Excel.

RESULTS AND DISCUSSIONS

According to experimental studies, the development of plants is directly related to environmental conditions and technology of cultivation. One of the main criteria for studying the technology of growing crops is a detailed analysis of indicators of germination, growth and development of the plant and its root system.

This makes it possible to determine the use of specific technological operations and justify the need and number of agricultural measures that enhance or inhibit the dynamics of plant growth and development. This issue is especially relevant on land plots with unfavorable agrophysical properties of the soil.

As a result of research (laboratory experiment № 1) on studying the effect of growth stimulant "Vympel" on germination, growth and development of corn, it was found that inoculation of seeds before sowing helps to increase plant germination. In the variant with overcompacted soil with the use of growth stimulant even in the minimum dose (400 g/t) there is an increase of 17 % germination energy and complete germination of corn seeds compared to the variant without growth stimulant. The positive effect of inoculation of seeds with biological products is associated with increased sowing properties of plant seeds. First of all, it improves the development of the root system and seedlings in general in the initial stages of ontogenesis. Thus, according to the literature data (Marenych & Yurchenko, 2016), inoculation of corn seeds with growth stimulant "Seed treatment" at a dose of 3 kg/ha increased the weight of seedlings and stem length of corn during seed treatment with growth stimulant compared to the control version by 10% and 20%, respectively.

According to the research results, the application of growth stimulant under conditions of soil overcompaction improves the development of the root system of corn, namely increasing its length, diameter and productivity, as evidenced by the calculation of the coefficient (Figure 1). Root productivity ratio characterizes the productivity of the root system.

The coefficient of determination R^2 indicates the percentage of effective scattering of the variable and is explained by the action of the variable factor. In our case, $R^2 = 0.8088$, ie the coefficient of root productivity by 81 % depends on the dose of inoculation of seeds with a growth stimulant. With increasing dose of growth stimulant, the productivity of the root system increases, which further increases crop yields.

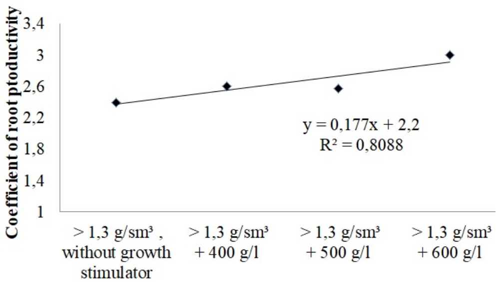

Figure 1. Linear regression model between of the coefficient of productivity of the root system of corn and the dose of growth stimulator under conditions of soil overcompaction

The use of seed inoculation before sowing helps not only to increase crop yields, but also to improve its quality (Căpățână et al., 2018; Oliynyk, 2021). The tendency to increase the biological yield during seed treatment with a growth stimulant is also noted in our studies (Figure 2).

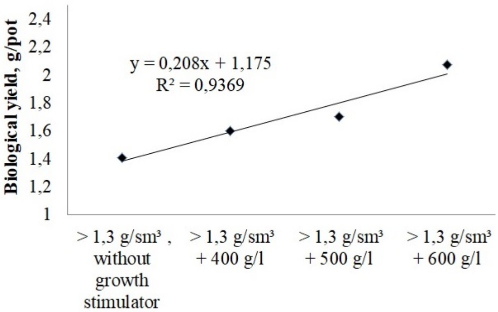

Figure 2. Linear regression model between of the biological yield of corn and the dose of growth stimulator under conditions of soil overcompaction

The dependence of the biological yield of corn on the dose of growth stimulant is statistically significant, 94 % of the variability of this indicator is due to the above model. The increase in biological yield due to inoculation, compared with the non-inoculated variant ranged from 14% to 47% depending on the dose.

Another way to improve the development of crops and their root system on soils with unfavorable agrophysical parameters is to optimize soil moisture and select an adaptive variety.

Thus, according to the results of laboratory-model experiment № 2 it was noted that soil moisture at 80% of s.w.c. helps to increase the diameter of the roots of both studied varieties by 10% compared to low moisture content (60% of s.w.c.) even under soil compaction. Soil moisture at the level of 80 and 100% of s.w.c. helps to increase the productivity of the roots of spring barley plants (Figure 3).

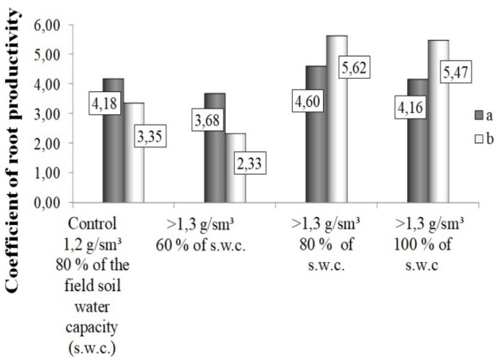

Figure 3. Influence of soil moisture levels on the coefficient of root productivity of spring barleys (a - intensive variety, b - semi-intensive variety) under conditions of soil overcompaction

Moreover, the productivity of the roots of semi-intensive varieties is characterized by 18-23% higher compared to plants of intensive varieties, which indicates a better adaptation of the roots of this variety to soil overcompaction.

The correlation between the biological yield of spring barley and the level of soil moisture was established by correlation-regression analysis (Figure 4).

The coefficient of determination is 0.8792 for the intensive variety and 0.8073 for the semi-intensive variety, which indicates that the level of biological yield of spring barley by 87 and 80% depends on soil moisture. In other words, as the soil moisture increases, so does the biological yield of spring barley.

In addition, even with a sufficient level of soil moisture, the yield of an intensive variety is almost 40% lower compared to a semi-intensive variety. And under conditions of moisture lack (60% of s.w.c.) the level of biological yield of intensive varieties is reduced by more than 50% compared to semi-intensive varieties grown in similar conditions.

Under the field conditions, along with the adaptive selection of spring barley varieties, sowing of mineral fertilizers was chosen as another method of adaptation. During the research (field small-scale experiment) it was found that the application of mineral fertilizers contributed to a more even and faster emergence of seedlings. During the growing season, there was a significant increase in the height of semi-intensive varieties compared to the intensive variety by 19% with the application of mineral fertilizers and conditions of soil overcompaction.

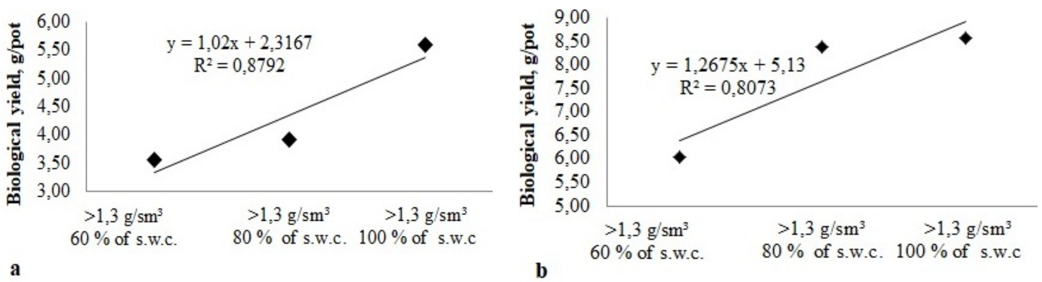

Figure 4. Linear regression model between of the biological yield of spring barley varieties (a - intensive variety, b - semi-intensive variety) and the moisture level under conditions of soil overcompaction

The influence of soil fertilizer on biometric indicators of spring barley varieties was also established (Figure 5).

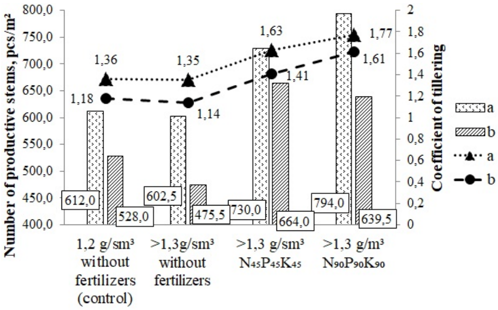

Figure 5. Influence of soil fertilizer on biometric indicators of varieties of spring barley (a - intensive variety, b - semi-intensive variety) under conditions of soil overcompaction

Thus, the number of productive stems of intensive variety under the conditions of soil overcompaction was 602 pcs/m^2, semi-intensive - 475 pcs/m^2. The application of mineral fertilizers increased this inicator by 21 and 39% (with application of $N_{45}P_{45}K_{45}$) and by 31 and 34% (with application of $N_{90}P_{90}K_{90}$), respectively. The coefficient of tillering had the same tendency to increase under the conditions of application of mineral fertilizers.

The dependence of spring barley yield on the dose of mineral fertilizers (Figure 6) is statistically significant - R^2 is 0.8297 and 0.9473, and therefore 82 and 94% of the yield of intensive and semi-intensive varieties is explained by this model.

However, the yield level of the semi-intensive variety was still slightly higher compared to the intensive variety under conditions of soil overcompaction. In the control variant (at the optimal soil density) the yield of the intensive variety was 33 hundreds kg/ha, which was 7 % more than the semi-intensive variety. But even in compacted variants, the intensive variety does not fully realize its biological yield and reduces the yield by 13% compared to the semi-intensive variety.

The advantages of intensive varieties are manifested, as a rule, only under favorable conditions, against the background of high cultivation technology and sufficient moisture. Under conditions of growing them on soils with unfavorable parameters and lack of moisture, intensive varieties not only do not realize their potential, but often form lower productivity than less productive varieties (Adamenko, 2006; Kolupaev & Karpets, 2010), but not demanding to growing conditions.

Therefore, semi-intensive varieties of spring barley should be sown on medium agrobackgrounds, lower soil fertility, after mediocre and satisfactory predecessors, with insufficient agro-technological support.

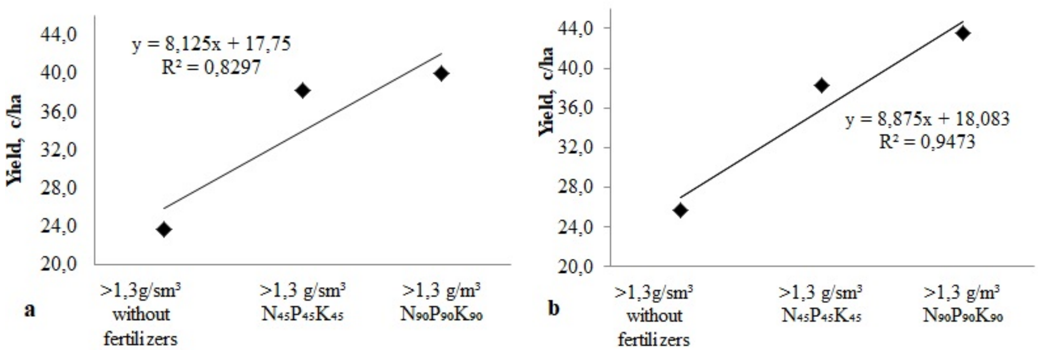

Figure 6. Model of linear regression between of the yield of varieties of spring barley (a - intensive variety, b - semi-intensive variety) and the dose of mineral fertilizers under conditions of soil overcompaction

CONCLUSIONS

The results of research show that the selected methods of adaptation of corn and spring barley to the overcompaction of the subseed sublayer of the soil provide increased germination, growth and development of crops, their root system and contribute to sustainable yields.

Correlations between corn yield and growth stimulant doses were found (r = 0.96); biological yield of barley varieties and moisture (r = 0.93 for intensive and r = 0.89 for semi-intensive varieties); biological yield of barley varieties and doses of mineral fertilizers (r = 0.91 for intensive and r = 0.97 for semi-intensive varieties) under conditions of soil overcompaction.

The best adaptation of semi-intensive varieties of spring barley to unfavorable agrophysical parameters of soil and growing conditions compared to intensive varieties has been established, which indicates the expediency of their cultivation on overcompacted soils.

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