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The deep fertilizers placement positively effects on their agronomic efficiency and yield of soybean and sunflower on chernozem

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ABSTRACT

The aim of the research was to study the effect of increasing the depth of mineral fertilizer placement on their agronomic efficiency for crops differed in root system architecture. Available NPK in soil, chlorophyll content in the leaves, and yield of sunflower and soybean were measured in the field small-plot experiments on Luvic Chernozem during three years. It was found a higher efficiency of $N_{60}P_{60}K_{60}$ placement for sunflower in form of mix of ammonium nitrate, ammophos and potassium chloride on 20-22 cm, and for soybean in form of nitroammophoska by two bands on 10-12 cm and 20-22 cm comparing to the common method of fertilizer applying by one band on the depth 10-12 cm. The maximum yield increase was 15% for soybeans, 36% for sunflower. The content of chlorophyll in leaves might be an additional indicator to optimize the technology of fertilizer application because it has close positive correlation with crops yield (P<0.01, R = 0.76-0.95). The obtained results prove the need for an individual approach in choosing the optimal fertilizer band placement for each crop separately. In general, increased depth of fertilizer band placement is recommend as a measure for adapting agricultural technology to unstable and insufficient moisture.

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1. Introduction

Ukraine is one of the leaders in the world market of oilseeds and grains due to a long farming traditions and a significant share of Chernozems. In 2020, sunflower occupied 23 % in the structure of sown areas and soybeans – 5 % [1]. However, modern climate change is accompanied by a trend towards drier springs and uneven distribution of precipitation in time and space that negatively affects to the spring crops, especially in the eastern and southern regions [2]. Climate aridization leads to the deterioration of nutrients uptake by plants due to their weak diffusion to the absorbing root surface [3]. Moreover, low transpiration rate, impaired active ion transport and membrane permeability reduce uptake by plant roots [4]. In case of uneven water supply, fertilizer systems should be close as possible to the mutable needs of plants during their vegetation.

Chernozems were formed on loess deposits contained from 30 to 70 % clay a particle that provides a high level of their fertility. From other side, it reduces the availability of phosphorus and potassium to plants due to their rapid non-exchange absorption by soil. Band application of fertilizers increases the nutrient use efficiency by minimizing of soil contact with fertilizer granules [5–9]. According to Jagła et al. [10] and Ao et al. [11], band fertilizers application allows reducing their doses and extending the sowing period under periodic moisture deficiency in early spring. The beneficial effect of fertilizer localization is highly dependent on depth of their placement. Singh et al. [12] determined the positive response of wheat grain yields to phosphorus fertilization at a depth of 10-15 cm compared to a depth of 5–7 cm in the semi-arid regions of northern Australia. Su et al. [13] found the same pattern in rapeseed (*Brassica napus L.*) crops, with the difference in yield being greater when rainfall was below normal during the growing season. According to Ma et al. [14], an increase in plant productivity and the efficiency of nutrient use occurs due to the proliferation of roots through local induction of nutrients. Shen et al. [15] proved that a localized NPK concentration can create the excellent root architecture with increased nutrient uptake efficiency share the same opinion. Dunbabin et al. [16, 17] showed that roots respond to heterogeneous nutritional conditions in two ways: i) by increasing the intensity of nutrient absorption; ii) by proliferation of roots in local zones and increasing the concentration of nutrients. Chen et al. [18] found that deep fertilization can promote rice root growth by increasing root length and diameter, and Wei Su et al. [19] obtained similar results with rapeseed.

Despite the above-mention, there is also evidence of insignificant change in crop yields from deeper fertilizer placement. Ma et al. [20] found that too deep localization of phosphorus fertilizers causes a deficiency of this element in plants at the seedling stage before the seedling roots can reach the phosphorus-rich zone. Therefore, although the localization of fertilizers in the soil improves the nutritional conditions of plants, the optimal parameters for the spatial placement of a fertilized band have not been studied enough.

In Ukraine, mineral fertilizers are mainly applied during pre-sowing tillage or sowing, and the depth of their placement ranges from 5 to 15 cm [21, 22]. Modern equipment makes it possible to create mineral fertilizer bands in the soil to a depth of up to 25 cm or divide them into two depths in order to provide comfortable conditions for plant nutrition as their root system develops. Unfortunately, there is a lack of information on what should be the optimal depth of fertilizer placement for crops with different root architecture in soils of Ukraine, taking into account climate changes. This is important for the part of Ukraine with the most continental climate, includes the Left-Bank Forest-Steppe where heavy loamy Haplic and Luvic Chernozems dominate in soil cover. However, the effectiveness of fertilizers there is limited by insufficient moisture supply during the growing season [23, 24]. The aim of the research was to determine the effect of increasing the depth of band fertilizer placement on NPK availability and productivity of crops with different root system architecture on Chernozem Luvic.

2. Objects and research methods

2.1 Experimental site and crops

Field experiments were conducted during 2018-2021 at the experimental site of "Experimental Farm "Grakivske" in Kharkiv region of Ukraine (49˚46′N lat., 39˚40′ E long). Chernozem Luvic heavy loamic at this site has pH_{KCl} – 5.3; organic carbon content by Tyurin method – 2.2 %; total nitrogen content – 0.2 %. Sunflower and soybean were grown at separate sites inside field with area 0.7 ha. As a forerunner for all two crops was winter wheat, therefore sites of the experiment were moving on experimental field according the crop rotation. Among the studied crops, soybean has a relatively short tap root and a large number of long lateral roots, most of them are located in the upper 20 cm soil layer. The tap root system of sunflower is more powerful and forms a large number of strong branched lateral roots at a depth of 10-40 cm.

2.2 Experimental treatments and design

The experiments were conducted as small plot research trials in six replications with completely randomized design.

The studies of all two crops were carried out according to the same scheme, where different types of fertilizers were applied to the band at different depths (Table 1).

Table 1
Scheme of experiments

№	Fertilizers	The rate of fertilizers, kg/ha	The number of fertilizer application bands	The depth of fertilizer placement, cm
1	No fertilizers	0	0	-
2	Nitroammofoska	$N_{60}P_{60}K_{60}$	1	10–12
3	Nitroammofoska	$N_{60}P_{60}K_{60}$	1	20–22
4	Nitroammofoska	$N_{60}P_{60}K_{60}$	2	10–12 and 20–22
5	Ammophos, ammonium nitrate and potassium chloride	$N_{60}P_{60}K_{60}$	1	20-22

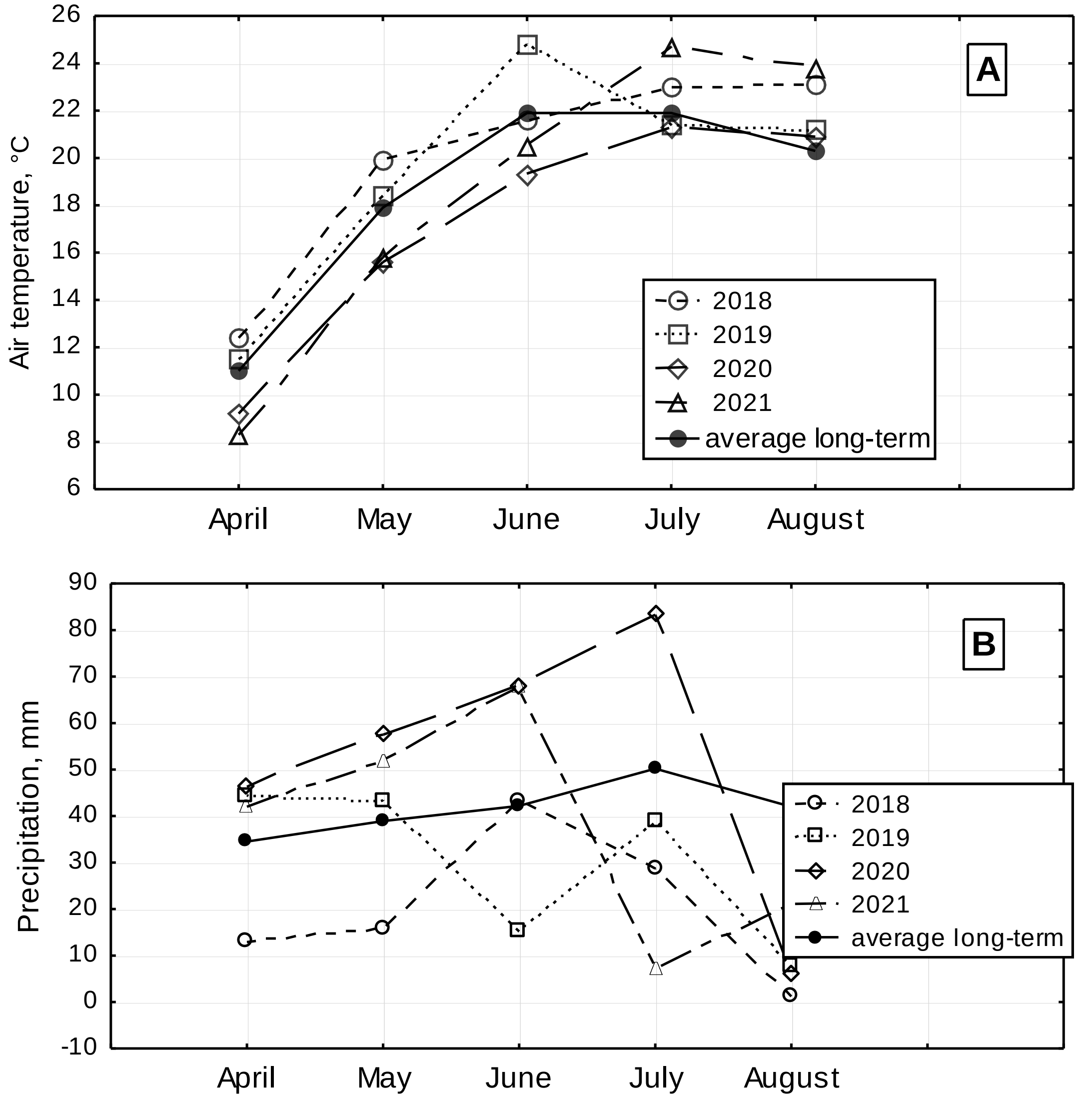
The scheme of experiments made it possible to compare the effectiveness of two most common trademark of solid mineral fertilizers – nitroammophoska (17-17-17) and fertilizer mixture from ammophos, ammonium nitrate and potassium chloride. As part of nitroammophoska, phosphorus is contained mainly in the form of slightly soluble $CaHPO_4$ $2H_2O$, citrate-soluble $Ca(H_2PO_4)_2$, and partially water-soluble $CaNH_4PO_4$. Ammophos contains 10-15% citrate-soluble $(NH_4)2HPO_4$ and 85–90 % water-soluble $NH_4H_2PO_4$, so phosphorus of this fertilizer is more available to plants.

The fertilizer band was placed at a distance of 4–5 cm to the side and in three different depth variations: 10–12 cm below the seed row, 20–22 cm below the seed row, and both bands simultaneously (10–12 cm and 20–22 cm). The application rate of NPK corresponded to the rates recommended for the Forest-Steppe zone of Ukraine [22] and was the same for all studied crops. Sunflower was grown in 2018–

2020, soybean – in 2019–2021. The cultivation technology was traditional for the Forest-Steppe zone of Ukraine.

2.3 Hydrothermal conditions

During the growing season in 2018–2021, rather contrasting hydrothermal conditions were observed (Figure 1). April–May and July–August 2018 were very dry. The precipitation was 1.7–2.7 times lower than the long-term average, and the air temperature was 1.4–2.0 °C higher. June–July 2019 and July 2021 were also dry and hot. In contrast, hydrothermal conditions were comfortable for growing crops in 2020. Thus, growing season was dry at the beginning of active plant growth in 2018, dry during the formation of generative organs in 2019, well moistened and relatively cool in 2020, and dry during the formation and maturation of soybeans in 2021.



(A - air temperature; B - precipitation)

Fig. 1. *Hydrothermal conditions of the study period*

2.4 Measurements and statistical analysis

Soil samples were taken in the fertilizer band (±5 cm from the placement of the granules) in the first half of the growing season and after harvesting crops. The mixed sample consisted of 6 individual samples, each 1 dm^3 (10×10×10 cm). The content of available phosphorus and potassium was measured after extraction with 0.5 n CH_3COOH by Chirikov method, nitrate nitrogen – photometrically with disulfophenolic acid, ammonium nitrogen – photometrically with Nessler's reagent. Soil water content was measured by the gravimetric method according to ISO 11465. The content of chlorophyll was measured in the middle part of leaves using SPAD-502 Plus portable device (manufactured by Minolta Camera Co. Ltd., Japan) according to the method described in detail by Süß et al. [25] and Uddling et al. [26]. Grain yield of soybean was calculated on 13–15% moisture content and sunflower seed grains – about 12 %. All the data were analyzed using STATISTICA 13.5.0.17. A least significant differences (LSD) were done using ANOVA at P<0.05 significance level.

3. Results

Although studied crops differ in the structure of root systems, their moisture requirements for seed germination are similar. The optimal stock of productive moisture in the 0–20 cm layer is around 21–30 mm [27, 28]. The moisture content in the soil arable layer at the beginning of the growing season for the research period ranged from 14.5 % to 16.8 %, and after harvesting - from 12.5 % to 19.0 %. This stock of productive moisture does not exceed 11 mm that is insufficient for formation of well-developed plants (Table 2).

At the beginning of the growing season, there was a slight increase in soil moisture in the fertilizer band with their deeper placement (by 20–22 cm): by 0.5-1.1 % for sunflower and by 0.1-0.6 % for soybeans (Table 2). The opposite trend was observed after harvesting. However, all this changes were within the least significant difference. Also, there were no significant differences in the content of mineral nitrogen, available phosphorus and potassium in the soil at different depths of fertilizer placement at the beginning of the growing season of the studied crops. Significant increases in these indicators were obtained with a shallow localization of the fertilizers band under soybeans (Table 3). It should be noted the difference 2.5–3.0 times in nitrogen content, and 1.1–1.6 times in phosphorus and potassium content in soil between variants of the experiment.

Table 2
Moisture regime of the soil at the depth of fertilization during the growing season and after harvesting, on average over the years of research

Field experiment tretaments	Soil moisture, % (during the growing season)		Soil moisture, % (after harvesting)	
	Sunflower	Soybean	Sunflower	Soybean
Control (without fertilizers)	15,2±2,9[1]	13,3±3,8	12,6±1,9	13,9±5,5
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm	14,6±2,8	12,7±2,9	13,9±3,1	13,5±5,8
$N_{60}P_{60}K_{60\ (complex)}$ 20-22 cm	15,1±3,6	12,7±2,0	12,9±2,3	13,3±5,6
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm and 20-22 cm	15,7±3,3	13,3±2,8	13,0±2,3	14,1±6,1
$N_{60}P_{60}K_{60\ (fertilizer\ mixture)}$ 20-22 cm	15,1±3,5	12,8±1,5	12,8±1,7	12,9±5,7
LSD(P≤ 0.05)	1,29	1,47	1,30	1,36

[1] ± standard deviation from averages by year of study

At the end of crop vegetation, the maximum amount of nutrients in the soil was noted at a deeper localization of the fertilizer band (Table 3). It is important that this applies specifically to available forms of NPK because their concentration in the fertilizer placement zone is primarily determined by the level of humidity and the intensity of granules dissolution, diffusion of soluble compounds, and their absorption by the soil solid phase. For these reasons, fertilizers placement at a depth of 20–22 cm has an advantage over placement at 10–12 cm, and nitroammophoska has an advantage over fertilizer mixture. This statement summarizes a general effect for the entire studied period. Previously published the detail data for spring barley shows that a deeper placement of fertilizers more contributes to an increase of available nutrients under unfavorable moistening conditions [29].

The deepening of the fertilizer band had a positive effect on the chlorophyll content in the plants leaves. The maximum chlorophyll content in sunflower plants was with fertilizers mixture applied to 20-22 cm, and in soybean – with nitroammophoska applied in two bands simultaneously (Figure 2).

Crop yield is critical to determining the optimum depth of fertilization, considering all of the above-mentioned aspects of water and nutrient regime, plant physiological response, and so on. Over the years of research, the highest yield of sunflower (3.74 t/ha) was obtained with the local application of nitroammophoska or fertilizer mixture to a depth of 20–22 cm (Figure 3). Soybeans shows the highest grain yield (2.17 t/ha) when was nitroammophoska applied in two bands to a depth of 10–12 cm and 20–22 cm. The increase in yield with a deep placement of fertilizer band compared with shallow placement ranged 32-44% for sunflower and 4-35% for soybean, depending on the year of research. A deeper placement of fertilizers ensured the payback of fertilizers by sunflower – 44 kg and soybean – 10.8 kg per 1 kg of NPK.

The response of sunflower to changes in the depth and composition of fertilizers did not depend on the weather conditions. Two fertilizer bands contributed to obtaining the maximum yield exceeded the option with band at 10–12 cm by 14 % in 2018, by 20 % in 2019 and by 29 % in 2020, and with deep application of fertilizer mixture – by 28, 34 and 44 % respectively.

Table 3
Nutritional regime of the soil at the depth of fertilization during the growing season and after harvesting, on average over the years of research

Field experiment tretaments	Nutrient content, mg/kg					
	N		P_2O_5		K_2O	
	Sunflower	Soybean	Sunflower	Soybean	Sunflower	Soybean
During the growing season						
Control (without fertilizers)	9,5±1,7[1]	15,5±1,1	81±30	95±3	97±33	91±8
$N_{60}P_{60}K_{60}$ (complex) 10-12 cm	22,8±8,9	23,7±3,1	137±68	145±27	150±13	126±19
$N_{60}P_{60}K_{60}$ (complex) 20-22 cm	25,9±8,2	26,8±5,7	137±66	145±25	151±31	128±22
$N_{60}P_{60}K_{60}$ (complex) 10-12 cm and 20-22 cm	22,5±8,8	23,9±2,3	127±69	142±22	147±29	122±15
$N_{60}P_{60}K_{60}$ (fertilizer mixture) 20-22 cm	23,1±4,0	22,9±2,0	104±55	127±19	121±38	112±17
LSD(P≤ 0.05)	2,92	2,65	6,5	6,6	3,94	3,7
After harvesting						
Control (without fertilizers)	10,0±7,2	11,1±7,7	101±15	94±7	80±18	86±10
$N_{60}P_{60}K_{60}$ (complex) 10-12 cm	11,4±7,6	21,1±4,8	153±24	137±36	80±21	109±19
$N_{60}P_{60}K_{60}$ (complex) 20-22 cm	10,0±4,2	27,5±5,2	163±24	139±37	85±21	118±19
$N_{60}P_{60}K_{60}$ (complex) 10-12 cm and 20-22 cm	13,8±7,3	20,0±8,1	120±11	125±29	83±14	108±16
$N_{60}P_{60}K_{60}$ (fertilizer mixture) 20-22 cm	12,1±9,2	19,1±5,7	100±28	111±18	76±16	101±15
LSD(P≤ 0.05)	0,68	2,58	3,7	1,7	3,4	2,1

[1] ± standard deviation from averages by year of study

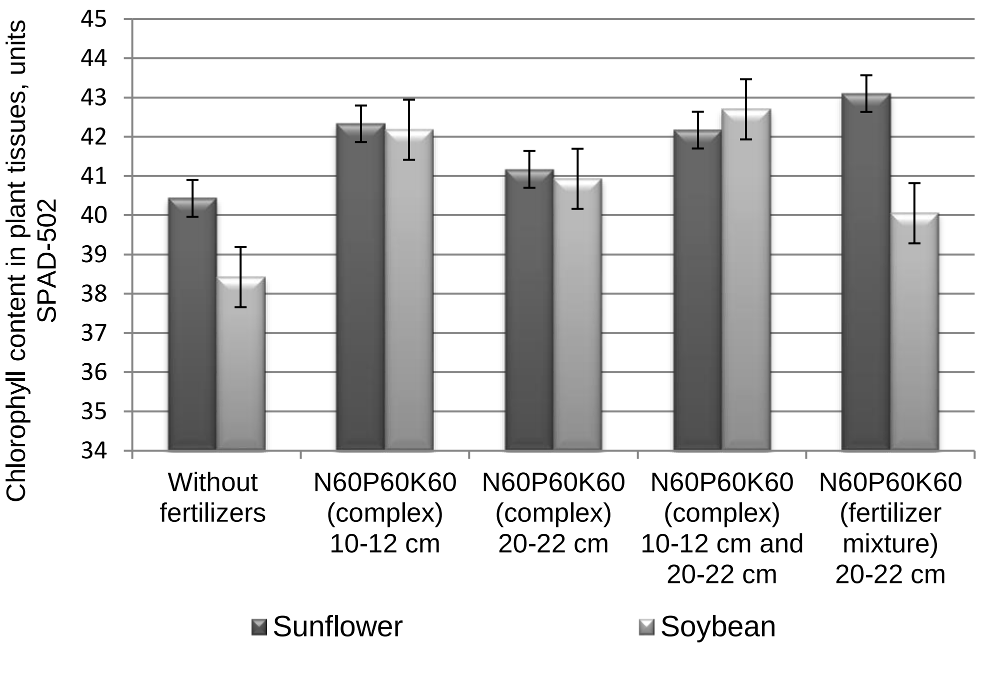


Fig. 2. *Chlorophyll content in plant leaves depending on the depth and kind of fertilizers*

It is important to note that the most significant increase in yield with deep fertilization was observed precisely in dry years, in particular, for soybean. Soybeans had the significantly higher yield with two fertilizer bands in 2019, and with deep placement of nitroammophoska in 2021 (when July-August was very dry) compared with shallow application. This may indicate that the effect of hydrothermal conditions of vegetation is more important for this crop than for sunflower. Similar results of soybean response to fertilization depth were reported by Farmaha et al. [6], Da Ros et al. [30] and Nkebiwe et al. [7]. Presumably, this may be related to the fact that the bulk of soybean root system locates in a layer of 0–20 cm, regardless of the level of soil moisture during the growing season, which was proven by Gebre and Earl [31]. The results of field experiment prove that optimization of the depth of fertilizer band placement is more important in conditions of moisture deficiency.

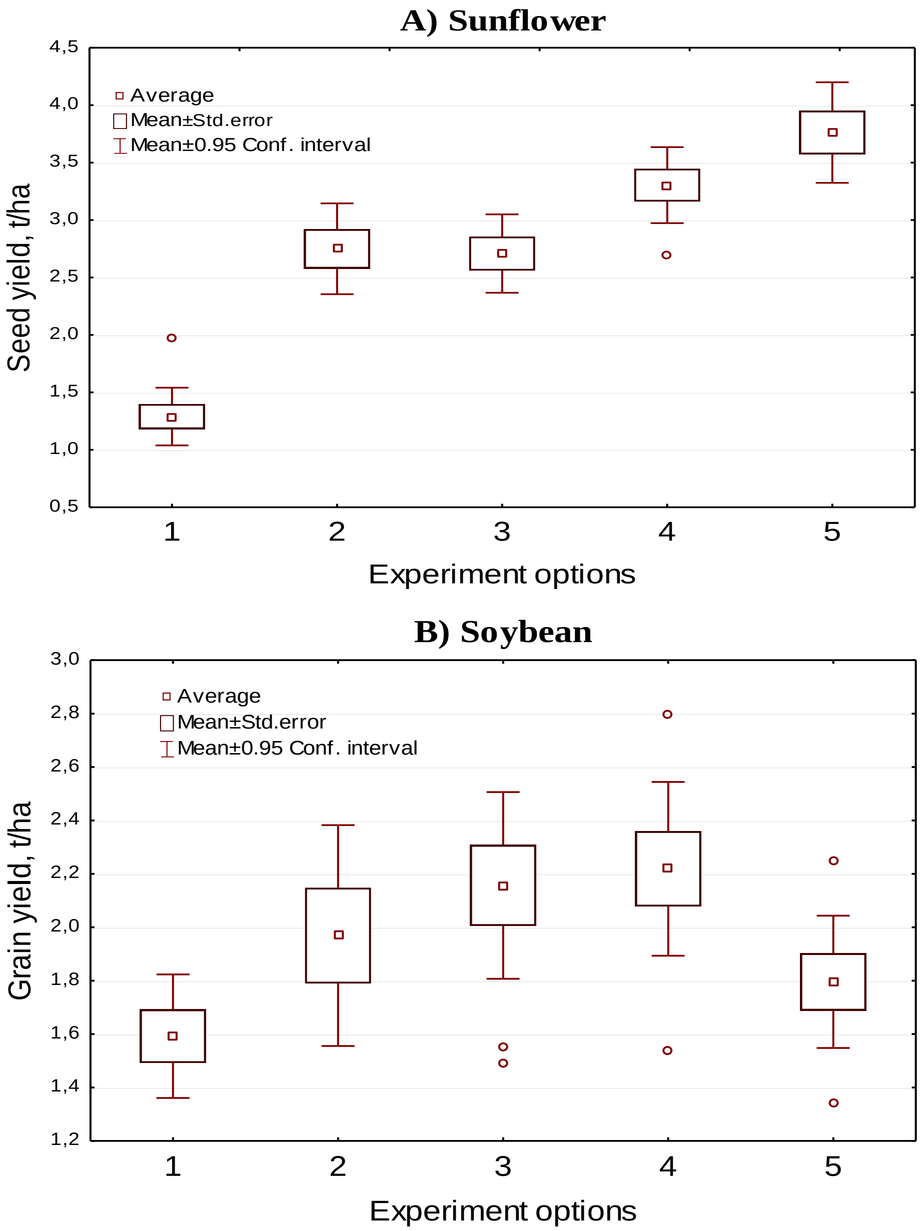


Fig. 3. *Crop yields depending on the depth of application and forms of fertilizers (three-year average value for barley published earlier*

According to the 4R concept of rational fertilization, the choice of the most appropriate form of fertilizers is an obligatory for optimizing the technology of their application [32]. The scheme of the experiment allowed comparing the deep application of complex fertilizers in the form of nitroammophoska with a similar application of a fertilizer mixture of ammophos, ammonium nitrate and potassium chloride. Combining NPK in one granule of complex mineral fertilizer nitroammophoska was more effective for soybean. Sunflower has a longer growing season so it more responded to the mixture of fertilizers when the granules of nitrogen, phosphorus, and potassium fertilizers are separated from each other.

4. Discussion

In the face of climate change, drying of the topsoil frequent occurs at the beginning of the growing season. Lack of avalable soil water leds to reduced nutrient availability that significantly limits plant growth [3, 33]. The working hypothesis of the research was increasing the depth of fertilizers placement to reducing the negative effects of drought. The results of field experiments confirm that hydrothermal conditions of the growing season and the depth of fertilizer band simultaneously affect the nutrient regime of soil. The effect of fertilizer placement was more noticeable at the end of the growing season. This fact mainly refers to phosphorus and potassium because their average content in the 5-cm zone around the fertilizer band at a depth of 20–22 cm was higher for all crops as opposed to a depth of 10–12 cm. We presume this is due to better soil moisture in the 20–22 cm layer during the growing season that contributes to faster dissolution of fertilizer granules and the corresponding diffusion transfer of $H_2PO_4^-$, HPO_4^{2-}, K^+ ions. Dianjun Lu et al. [34], Szulc et al. [35] suppose that the localization of fertilizers: i) reduces the fixation of nutrients in the soil; ii) increases their availability for plants; iii) enhances the nutrients use efficiency by plants. Kraska et al. [36] noted that deep application of mineral fertilizers increases the content of available phosphorus in the soil. According to Lu et al. [8] and Jiang et al. [37], a diffusion foci of increased concentration of phosphorus and mineral nitrogen is formed around the fertilizer band which provides improved plant nutrition for a long time. Undoubtedly, these facts positively affect both the growth processes and the efficiency of plant photosynthesis.

The issue of the influence of mineral nutrition conditions on the chlorophyll content in plants is well described in the scientific literature [38, 39]. On the example of many crops, the positive effect of different doses, types and methods of fertilization on the chlorophyll content in the leaves, and, accordingly, on the yield, has been proven. In our studies, a strong positive correlation also was found (r = 0.88 at P<0.05) between chlorophyll content in plants and crops yield. This confirms the important diagnostic value of the chlorophyll content as an auxiliary indicator for choosing the best fertilizer application depth. The tightness of the relationship between the SPAD-502 indicators and crops yield was different: for sunflower r = 0.91, for soybeans r = 0.76 (Figure 4). According to the linear regression equations in Figure 4, the largest increase in yield with an increase per unit of the SPAD-502 indicator was for sunflower – 0.86 tons, while for soybeans it was only 0.12 tons, respectively. Firstly, this is due to a significant increase in sunflower yields under application of fertilizers in general, and secondly, it's very positive response to a deeper localization of fertilizers.

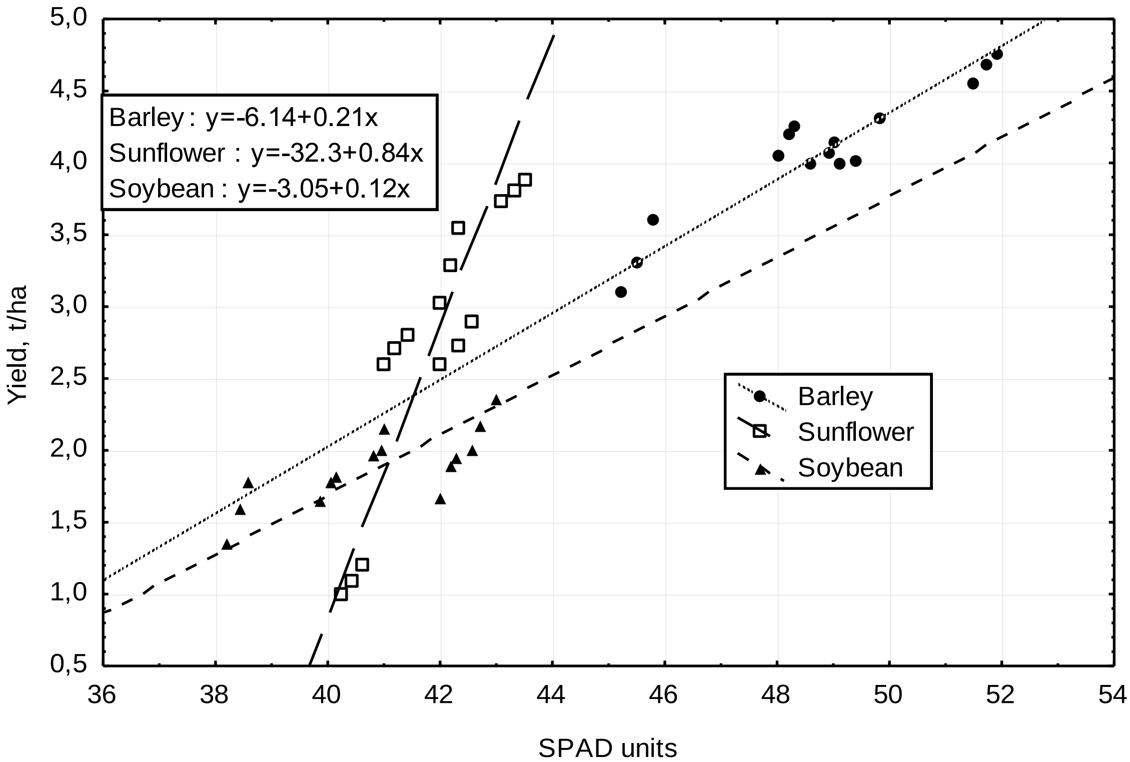
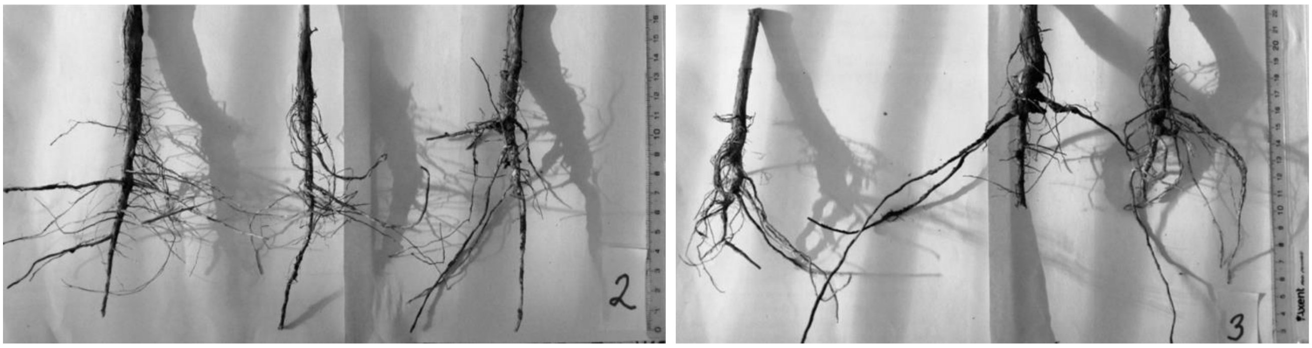


Fig. 4. *The relationship between chlorophyll content in plants and crops yield* (three-year average value for barley published earlier [29]

Our preliminary three-year studies with barley [29] also showed a close relationship between the content of chlorophyll in leaves and grain yield. The relationship between the SPAD-502 indicators and grain yield was for barley r = 0.95 and according the linear regression equation (Figure 4), the increase in yield with an increase per unit of the SPAD-502 indicator was for barley 0.21 tons.

It is known that the content of chlorophyll in leaves depends on the phase of plant development, the type and variety of agricultural crops that also affects the tightness of the correlation between this indicator and yield [40, 41]. Despite this, there are a lot of confirmation positive correlation (from r = 0.92 to r = 0.70) between chlorophyll in SPAD units and indicators affected yield [42–46]. Hosseinzadeh et al. [38] used chlorophyll content as an index to determine plant stress resistance and their response to adaptive measures. Nemeskeri et al. [47, 48] proved that SPAD chlorophyll measurement assess well drought tolerance of genotypes and productivity of some crop varieties grown under moisture deficiency. Above-mentioned as well as our results indicate the possibility of using data on the content of chlorophyll in plants as an auxiliary criterion for optimizing the fertilizer system (method of application, type, dose, etc.).

The difference in plant response to the methods and forms of fertilization that was find out in our research, confirms the conclusions of Ma et al. [20] about the importance of taking into account all edaphic and hydrothermal conditions to right choice the optimal depth of fertilizer application. According to Shen et al. [15], the phenotypic and physiological plasticity of plants develops due to the proliferation of lateral roots in response to a heterogeneous nutrients supply to the upper soil layer and an increase in the assimilation of nutrients in zones provided with them. This is one of the most important reasons for the positive response of crop yields to deep fertilization, specifically for wheat [12], lupine [49], rapeseed [50], corn [9]. A similar trend towards better branching of the root system is also visually observed in our experiment. When fertilizers were applied at 20–22 cm, the plants formed a greater number of well-developed lateral roots than at 10–12 cm (Figure 5 and 6).



A B

Fig. 5. *Soybean root system in case of fertilizers placement at the depth 10–12 cm (A) and 20–22 cm (B)*

A B

Fig. 6. *Sunflower root system in case of fertilizers placement at the depth 10–12 cm (A) and 20–22 cm (B)*

Taking into account the well-known fact of the low migration ability of phosphorus and potassium fertilizers in the soil [51, 52], the arable soil layer is considered to be the most heterogeneous in terms of the concentration of these nutrients in the time interval between banding fertilization and soil tillage for the next crop. This is also confirmed by the data of Lu et al. [8], who found a decrease in the concentration of water-soluble and available P in the soil at a distance of 3.5 cm from the monocalcium phosphate granule and 5.5 cm from the diammonium phosphate granule. The formation of powerful lateral roots improves nutrition by covering a larger volume of soil in the upper layer that can be considered as an auxiliary mechanism for plant adaptation to insufficient moisture [53, 54]. Kang et al. [55] showed that deep placement of phosphate fertilizers stimulates root growth and has a positive effect on the yield of a drought-tolerant wheat variety. According to Klimešová and Streda [56], the relationship between barley root density and yield was observed only in the 20-40 cm layer, with a significant positive correlation noted in a dry year.

Meta-analysis by Nkebiwe et al. [7] of the results of 39 field experiments showed that winter and spring wheat, corn, sorghum, rapeseed, potatoes, rice, Chinese cabbage and sugar beets increased yields with deeper fertilizer placement, while winter rye, cauliflower, lettuce and soybeans almost did not reacted to it. These data prove the importance of an individual approach to choosing the depth of the fertilizer band for each crop. The yield data in our experiment (Figure 3) confirms that each crop may have its own best combination of fertilizer placement depth and form. In particular, sunflower responses best to application fertilizer mixtures at 20–22 cm, soybean and sunflower – nitroammophoska in two tapes simultaneously (10–12 cm and 20–22 cm). The data in Figure 3 confirm that due to the deep application of fertilizers, the increase in the yield of soybean and sunflower grains ranged from 4 to 44% compared with their shallow placement. This gives grounds to consider an increase in the depth of mineral fertilizers placement as one of the measures for adapting farming technologies to unstable and insufficient moisture conditions. In the future, even more dry conditions are predicted in the first half of the growing season that is especially harmful to early cereals in the left-bank part of the Forest-Steppe of Ukraine [57, 58]. In this regard, the deep localization of mineral fertilizers is expedient for this group of crops, as a component of smart growing technologies.

5. Conclusions

Increasing the depth mineral fertilizers placement is a technique that can mitigate the negative impact of current climate change on the cultivation of field crops on the Chernozem Luvic in the Forest-Steppe of Ukraine. However, the optimal placement depth and form of mineral fertilizers depends on the crop and the weather conditions of the year.

On average, over a three-year period, the highest yield and agronomic efficiency of fertilizers was obtained for sunflower when was applied a fertilizer mixture of ammophos, ammonium nitrate and potassium chloride by 20–22 cm, for soybeans and sunflower – nitroammophoska in two tapes at the same time (by 10–12 and 20–22 cm).

The deep fertilizers placement contributes to increase the content of available nitrogen, phosphorus and potassium in the soil around band of their application, especially at the end of the growing season.

The indicator of chlorophyll accumulation in plant leaves strongly correlates with the yield of sunflower (r = 0.91) and soybean (r = 0.76), but does not change significantly with an increase in the depth of fertilizer placement so it can only be auxiliary criterion for optimizing the fertilization technology.

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Позитивний вплив глибокого внесення добрив на їх агрономічну ефективність та урожайність сої і соняшнику на чорноземі

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Метою статті було висвітлення результатів вивчення впливу збільшення глибини внесення стрічки мінеральних добрив на їх агротехнічну ефективність для культур, що відрізняються будовою кореневої системи. У польових дослідженнях, проведених на чорноземі опідзоленому протягом трьох років, визначали вміст мінерального азоту, доступних форм фосфору і калію у ґрунті, вміст хлорофілу у листі рослин та врожайність соняшнику і сої. Встановлено високу ефективність розміщення стрічки добрив ($N_{60}P_{60}K_{60}$) для соняшнику, у вигляді тукосуміші аміачної селітри, амофосу та хлористого калію, на глибині 20–22 см, а для сої, у вигляді нітроамофоски, у дві смуги на глибині 10–12 і 20–22 см порівняно із звичайним способом внесення добрив однією стрічкою на глибині 10–12 см. Максимальний приріст урожаю становив 15 % для сої та 36 % для соняшнику. Визначено, що вміст хлорофілу у листі рослин може бути додатковим показником для оптимізації технології внесення добрив, оскільки має тісний позитивний зв'язок з урожайністю культур ($P<0{,}01$, $R = 0{,}76–0{,}95$). Здобуті результати доводять необхідність індивідуального підходу до вибору оптимального розміщення стрічки удобрення під кожну культуру окремо. Загалом збільшення глибини закладання стрічки добрив рекомендується як захід адаптації агротехніки до нестабільного та недостатнього зволоження протягом вегетації.

***Ключові слова**:* стрічкове внесення добрив, доступні елементи живлення, гідротермічні умови, хлорофіл, урожайність

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