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Effect of tillage on productivity of crop rotation and nitrate contain in topsoil under unstable of atmospheric precipitation

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ABSTRACT

The aim of the work was to identify the presence of a relationship between the productivity of grain-row crop rotation and the content of nitrates in the topsoil with different ways of its main tillage. Eight-year monitoring was conducted within a long stationary field experiment on the territory of the experimental farm of NSC ISSAR in Donetsk region. The content of nitrate nitrogen in chernozem ordinary was determined on three soil treatment options - moldboard ploughing, subsurface non-turning soil tillage and no-till. At the same time, the dynamics of weather conditions was observed and the hydrothermal coefficient of Selianinov (HTC) was calculated. Statistical data processing was performed by correlation, regression and ANOVA analysis in a sample of the results of 729 individual observations. It is shown that after a two-year drought, an increase in yield occurs along with an increase in the content of nitrates in the soil on all variants of soil treatment. However, a year after the overmoistening, the yield decreases, despite the still high level of nitrate nutrition. In years with critically low humidity, the greatest yields are recorded on moldboard plowing. By comparing the treatment efficiency without soil turnover and the conventional moldboard plowing, we determined the conditions under which minimization of tillage is advisable. With an increase in the degree of minimization of tillage, the positive peak on the graph of the relative yields dynamics decreases and the negative one deepens. With no-till, the productivity of crops decreases in years with a HTC less than 0.6 at the same time as a decrease in the nitrate content in the soil. For no-till, a positive correlation was also determined between the level of nitrate content in the soil last year and the crop yield in the following. It was found that the non-use of plowing increases the risk of negative effects of excessive soil moisture if the nitrate content is high. It has been proven that a lack of nitrogen is not a factor in determining yields under subsurface non-turning tillage. However, with no-till, the decrease in yield is due to a decrease in the content of nitrate nitrogen in the soil, which has a long-term effect. Based on this, it is possible to predict the effectiveness of the direct sowing system. The regression analysis determined the dependence of the relative yield for no-till on the relative content of nitrates in the soil of the previous year (r = 0.950).

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1. Introduction

Many scientists note the existence of a link between the content of nitrates in the soil and the yield of crops [1-6]. In particular, the dense dependence of spring wheat yield [3], as well as fertilizer efficiency [5], on the content of nitrate nitrogen in the soil was found. The possibility of forecasting the yield of winter rye is shown depending on the level of crop provision with nitrate nitrogen [4]. The optimum content of nitrates in the soil for corn [1, 2] was established: the highest yield was determined by the content of nitrate nitrogen in the arable layer about 60 mg / kg of soil in the phase of 4-5 leaves.

Intensive use of Ukrainian soils undergoes significant losses of nutritional elements, including mineral nitrogen (S.A. Baliuk, V.V. Medvedev, A.D. Balaev, O.L. Tonkha, M.V. Gavrilyuk et al., 2018) [7-9], which necessitates the rejection of traditional tillage. The directions of scientific research on soil protection are formed in connection with the trends of both global climate change and regional changes [9].

Due to the increasing moisture deficit, which may be accompanied by incomplete use of soil nutrients (eg, residual nitrates or phosphates) [9], the transition of modern agriculture to soil protection technologies actualizes the direction of studying the peculiarities of the formation of soil nitrogen regime and its impact on the productivity of agricultural crops under different methods of tillage [10] under certain meteorological features of the region.

There is evidence of deterioration [11] and improvement [12, 13] of the nitrogen regime for the failure to turnover the soil layer during cultivation. In the literature, there are examples of the lack of influence of cultivation on the accumulation of nitrates in chernozem ordinary [14], as well as the lack of advantages of the failure to turnover the soil layer, especially in the long-term drought [9, 15]. According to the Italian scientists, the reduction of nitrate nitrogen content in the soil for the no-till is associated with greater dependence on weather conditions than for plowing [16]. The unevenness of the estimates of the impact of plowing failure on the nutrient regime of

the soil is due to the heterogeneity of meteorological conditions in the observation sites

In addition, according to [17, 18], moldboard plowing advantage (compared to the subsurface tillage) on the nitrate content in the soil is not always form the advantage in yields, which essentially depends on weather conditions and crop rotation [18].

Based on the aforementioned, the aim of the research was formed - to find out the existence of a connection between the productivity of the grain-growing crop rotation and the content of nitrates in the arable layer of soil under plowing, the subsurface non-turning soil tillage and zero tillage in the soil-climatic conditions of the Donetsk region.

2. Object, methods and research conditions

The work was carried out in 1997-2005 in the framework of research on field stationary experiment on the territory of the experimental farm "Donetske" of National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky» in the Yasynuvatsky district of the Donetsk region. The region is located in the natural zone Steppe. The experimental field has the following coordinates: 48°19'39.3"N 37°46'12.9"E.

Soil - chernozem ordinary. Grain-growing crop rotation includes the following crops: maize for silage; winter wheat; maize for grain; spring barley; sunflower; grain mix; winter wheat; maize for grain.

The types of tillage were studied: conventional moldboard plowing; subsurface non-turning soil tillage; zero tillage (no-till).

The entry into rotation was carried out simultaneously by three fields from the 1st, 2nd and 3rd crops of the rotation.

Repetition of options was triple; the area of a single experimental plot - 1600 m^2.

Soil sampling from a layer of 0-30 cm. Measurement of the content of NO3 was carried out using the Grandval-Lyag method (with disulfophenoic acid and photocolorimetric determination). Meteorological data were obtained from the observation meteopost in the village Sukha-Balka Yasynuvatsky district (48°19'37.4"N 37°45'53.1"E). Statistical data processing was done by correlation, regression and ANOVA analysis in a sample of 729 individual observations.

Meteorological conditions for conducting research characterized as contrast. The start of field experiment (1997) was carried out in the year with intensive atmospheric humidification (hydrothermal coefficient of Selianinov (HTC) 1,25). In the first two years of crop rotation (1998 and 1999) the HTC was 0.53 and 0.64, which corresponds to the conditions of the dry farming zone [19]. The following years (2000, 2002, 2003, 2004) characterized by sufficient moisture (HTC 0.94, 0.91, 1.06 and 1.11 respectively); 2001 is very humid (HTC 1.67), final, 2005 - again arid (HTC 0.58).

3. Results and discussion

Reduced productivity of crop rotation detected due to the failure of moldboard plowing: under subsurface non-turning soil tillage by 11 %, under no-till by 36 %.

The total amount of main crop production in feed units is 34.36 t/ha for plowing, 30.67 t/ha for subsurface tillage, and 21.89 t/ha for no-till. Lower productivity of crop rotation due to refusal of plowing is observed against the background of a decrease in the average content of nitrates in the soil: 35.8 mg/kg for plowing, 33.9 mg/kg for subsurface tillage, 26.4 mg/kg for no-till (the smallest significant difference 2.3 mg/kg of soil).

Table 1
Dynamics of crop yields in different tillage methods

Tillage	Crop yields, tons of feed units per hectare							
	1998	1999	2000	2001	2002	2003	2004	2005
	HTC 0,53	HTC 0,64	HTC 0,94	HTC 1,67	HTC 0.91	HTC 1.06	HTC 1.11	HTC 0.58
Moldboard plowing	3.40	3.81	9.19	6.49	2.75	2.16	2.65	3.14
Subsurface non-turning tillage	3.14	3.44	8.18	5.97	1.28	2.28	2.57	3.10
Zero tillage (no-till)	1.92	3.34	5.94	4.47	0.69	1.34	2.13	1.74
LSD(,05)	0.50	0.96	1.35	0.65	0.49	0.57	0.29	0.22

Visible (especially for plowing) is a general increase yield during the first two years with sufficient and excessive atmospheric moisture - 2000 (HTC 0.94) and 2001 (HTC 1.67) after two-year drought in 1998-1999. After excessive humidification in 2001, there is a decrease yields in 2002, however, this fall is the smallest under plowing.

For no-till, unlike intensive tillage, the conditions of dry years - 1998 (HTC 0,53) and 2005 (HTC 0,58) are marked as extreme, when yields decrease for zero cultivation, but not as much as in 2002, after excessively wet year.

Under the HTC 0.64 in the second arid year (1999), zero tillage contributes to an increase in the number of products to 3.34 tons per hectare, which does not statistically differ from the efficiency of intensive tillage technologies, whose productivity under such conditions remains at the level of the previous arid 1998 year.

The average yield in non-stressful conditions varies in the plowing from 2.16 to 38.1 t / ha of feed units, for subsurface non-turning tillage - from 2.28 to 3.44 t / ha, for no-till - 2.13-3, 34 t / ha.

The results of determination of the content of nitrates in the arable soil layer during the growing of crop rotation crops are presented in the table 2. Comparison of these with yield data indicates that the total increase in yields in the first two years of sufficient and excessive moisture (2000 with HTC 0.94 and 2001 with HTC 1.67) after two years of drought (1998-1999) occurs on the background of significant increase in the content of nitric nitrogen in the soil: maximum for plowing and minimum for zero tillage (Table 2).

Table 2
Dynamics of the nitrates content in the arable soil layer

Tillage	Nitrate content, mg/kg of soil							
	1998	1999	2000	2001	2002	2003	2004	2005
	HTC 0.53	HTC 0.64	HTC 0.94	HTC 1.67	HTC 0.91	HTC 1.06	HTC 1.11	HTC 0.58
Moldboard plowing	16.08	18.40	46.99	50.11	52.73	40.37	32.04	29.42
Subsurface non-turning tillage	15.14	19.16	46.51	48.74	48.60	37.04	27.86	28.09
Zero tillage (no-till)	12.32	16.10	19.85	37.92	42.46	30.60	28.54	23.58
LSD (.05)	3.20	1.41	21.52	10.19	15.16	8.33	3.31	4.00

Instead, a significant decrease in production in 2002 (HTC 0.91) occurs against the backdrop of an increase in the content of nitrates in the soil after excessive moisture in 2001 (HTC 1.67) on all variants of tillage.

Low yields for the no-till in arid years (1998 with HTC 0.53 and 2005 with HTC 0.58) are accompanied by a low level of nitrate contents in soil. For example, in 2005 the content of nitrates in the soil for the no-till is 17% less than in the previous one.

It should be noted that the HTC 0.64 second consecutive drought year (1999) for zero tillage contributes to an increase in the content of nitrates in soil by 31%, by 27% for subsurface cultivator tillage, and by 14% - for plowing. That is, the abandonment of soil turnover positively affects the content of nitrates in the arable layer of soil during the arid period; for no-till it manifests itself only for the second arid year, and for subsurface non-turning tillage it manifests itself during the two years of drought.

In general, during the study period, we have two critical points, which we will note on the background of increasing nitrate nitrogen content in the soil (Fig. 1). The first is the output from the two-year (1998-1999) drought, accompanied by a significant increase in the yield, and the second - the output from one-year over wetting with a significant decline in yields (calculated in feed units).

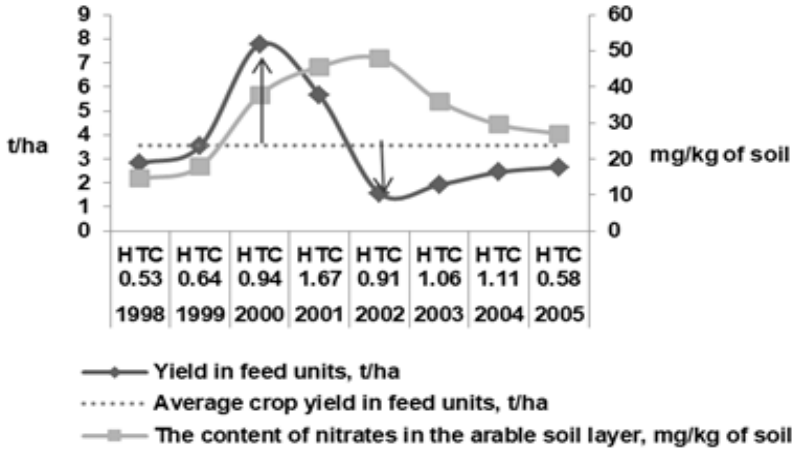

Fig. 1. *Critical conditions for the formation of the crop (average data in the experiment)*

The plowing characterized by a maximum increase in yield after two years of drought and a minimal decrease in yield after one year of excessive moisture (Figure 2). With increasing degree of minimization of soil tillage, the positive peak of crop dynamics during the crop rotation decreases and the negative deepened. However, for the no-till, the yield also reduced in the years from the HTC less than 0.6 when the level of nitrate feed reduced.

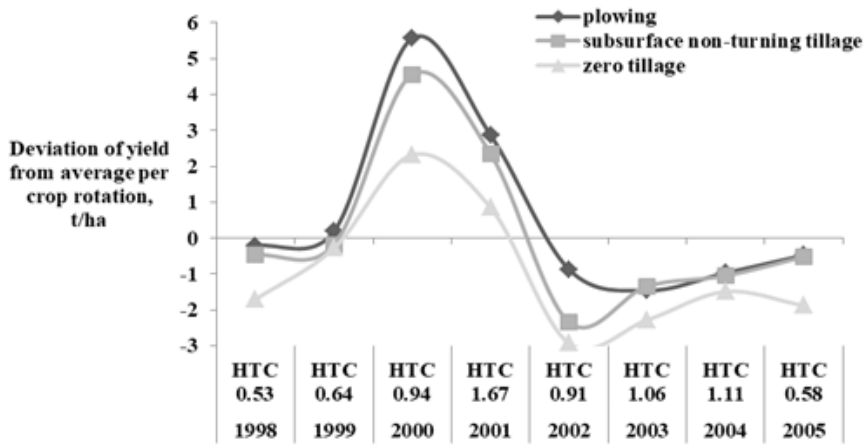

Fig. 2. *Deviation from the average per crop rotation of the amount of plant products, feed units*

Comparing the efficiency of tillage without plowing with the efficiency of traditional plowing can determine the conditions under which minimization of soil tillage is appropriate (Fig. 3).

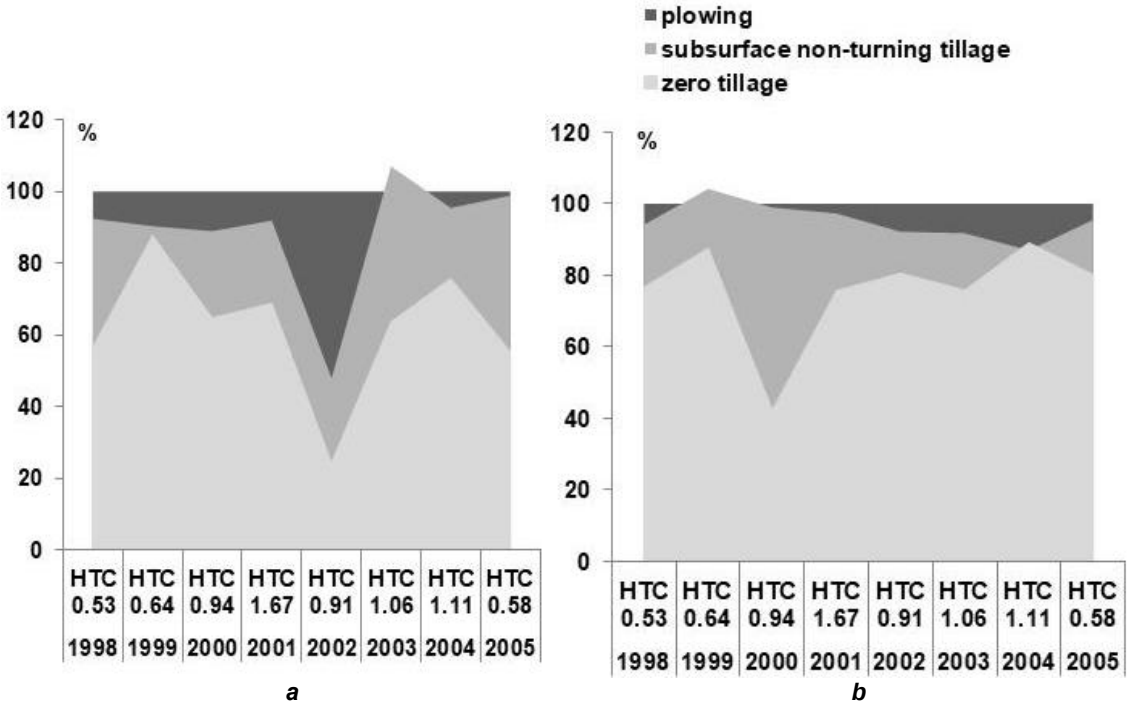

Fig. 3. *Relative yields (a) and content of nitrates in the arable layer of soil (b) during the crop rotation in different methods of tillage*

Thus, the lowest yield for abandonment of plowing is observed in the following year after over wetting and it is 47.9 % relative to plowing for subsurface cultivator tillage, for no-till it is 24.3 %, although in other years the index does not fall below 89.0 % and 55.4 % respectively. That is, the efficiency of minimizing tillage is the maximum reduced in the years preceding over wetting, when the high level of nitrate nitrogen is form in the soil. Given that excessive nitrogen content increases the susceptibility of plants to diseases and slows down the transition to the reproductive phase [20], it can be argue that the abandonment of plowing increases the risk of negative consequences of over wetting, which increases by increasing the amount of plant residues on the soil surface.

The most effective for subsurface non-turning tillage, when the relative yield varies from 95.5 % to 107 % compared to the plowing, is the next three years after the maximum drop in yield caused by over wetting, irrespective of hydrothermal conditions and a decrease in the level of nitrate content in the soil by 4.5-13 % relative to plowing. The first year of drought for subsurface cultivator tillage is somewhat more effective compared to plowing (in 1998 the yield was 92.4 % and 98.8 % in 2005) than the second (90.4 % in 1999, despite increasing nitrate content in the soil to 104.1 %).

Thus, for subsurface non-turning tillage, the period after drought is more critical because it occurs at relatively high nitrate nitrogen content in the soil, compared with the period after the wet year, when the nitrate content is less than on the plowing.

In addition, thus, we state: the factor determining yields for subsurface non-turning tillage under experimental conditions is not a lack of nitrogen. Regression analysis revealed even negative, although not dense (r -0.368), correlation of relative yield and nitrate content in the soil of the previous year for subsurface non-turning tillage.

The most effective for no-till is the second year of drought, when the relative yield is 87.7%, and the third year after over wetting with a relative amount of 75.8%, what is observed at the maximum nitrate nitrogen content in soil up to 87.5 and 89.1% relative plowing. It follows from this that the relative reduction in the content of nitrate nitrogen in the soil for the no-till is a determining factor in reducing yields relative to plowing.

The regression analysis determined the dependence of the relative yield for no-till from the relative content of nitrates in the soil of the year before:

$$y = 1{,}0953x - 21{,}277,\ r = 0{,}950$$

where x – relative content of NO_3 in the arable soil layer of the previous year, as a percentage of the plowing; y – the relative amount of feed units of plant products next year for no-till, as a percentage of plowing.

That is, the long-term effect of the level of soil saturation with nitrate nitrogen for the no-till technology is determined, which makes it possible to predict the direct sowing efficiency of next year by the level of nitrate content in the arable soil layer of the previous year.

4. Conclusions

Minimization of soil cultivation reduces the productivity of grain-crop rotation in contrasting weather conditions.

The rejection of plowing increases the risk of negative consequences of over wetting at elevated levels of nitrates in the soil, in particular, due to the development of diseases, which is facilitate by the presence of plant residues on the soil surface.

A lack of nitrogen is not the determining factor for yield by subsurface non-turning tillage.

The reduction of yield for the no-till is form by a decrease of the nitrogen mobility in the soil, which has a long-lasting effect, because of which it is possible to predict the efficiency of the direct sowing system.

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Вплив способу обробітку ґрунту на продуктивність сівозміни і вміст нітратів в орному шарі за нестабільності атмосферного зволоження

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Метою було виявити наявність зв'язку продуктивності зерно-просапної сівозміни та вмісту нітратів у ґрунті за різних способів його основного обробітку. В умовах польового досліду на території Донецької області впродовж 8 років проводили моніторинг вмісту нітратного азоту в орному шарі чорнозему звичайного на трьох варіантах обробітку ґрунту – оранки, безвідвального плоскорізного та нульового (*no-till*). Одночасно спостерігали динаміку погодних умов і розраховували гідротермічний коефіцієнт (ГТК). Статистичну обробку даних виконано кореляційним, регресійним та ANOVA аналізом у вибірці 729 індивідуальних спостережень. Показано, що на всіх варіантах після дворічної посухи відбувається збільшення врожаю на фоні підвищення вмісту нітратів у ґрунті, а через рік після перезволоження врожайність падає, незважаючи на високий рівень нітратного живлення. У критичні за зволоженням роки найбільші врожаї зафіксовано на оранці. Співставленням ефективності обробітків без обертання пласта і традиційної відвальної оранки визначено умови, за яких мінімізація обробітку ґрунту є доцільною. Із підвищенням ступеню мінімізації обробітку ґрунту зменшується додатний пік на графіку динаміки відносних врожаїв і поглиблюється від'ємний. Для *no-till* формується зниження продуктивності культур у роки із ГТК менше 0,6 на фоні зниження рівня нітратного живлення. Для нульового обробітку визначено позитивний корелятивний зв'язок між рівнем умісту нітратів у ґрунті минулого року і кількістю продукції наступного року. Виявлено, що відмова від обертання пласта посилює ризик негативних наслідків перезволоження за підвищеного рівня нітратів у ґрунті. Доведено, що нестача азоту не є визначальним фактором урожаю за безвідвального плоскорізного обробітку ґрунту. За *no-till* падіння врожайності обумовлюється тривалим зменшенням вмісту нітратного азоту в ґрунті, на підставі чого можливим є прогнозування ефективності системи прямого посіву. Регресійним аналізом визначено залежність відносної врожайності за *no-till* від відносного вмісту нітратів у ґрунті позаминулого року (*r=0,950).*

Ключові слова: *безвідвальний плоскорізний обробіток; гідротермічний коефіцієнт Селянинова; ГТК; нітрати; нульовий обробіток; оранка; урожайність культур.*

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