

Winter wheat growing in Ukraine: ecological assessment of technologies by the influence on soil fertility

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Received December 12, 2018; accepted December 27, 2019.
Delo je prislo 12. decembra 2018, sprejeto 27. decembra 2019.

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Abstract: Modern technologies of winter wheat growing need to be improved taking into account the results of ecological evaluation of their impact on soil fertility indices. We aimed to assess the technologies of winter wheat growing in different soil and climatic conditions of Ukraine by their influence on soil fertility. It is known that in order to estimate ecological safety of crop growing technologies, it is advisable to use a method based on identifying negative impacts on soil fertility. We propose the group of deviation values from the optimum as follows: (i) strong, which leads to an unsatisfactory ecological condition (> 50 %), (ii) average that provides a satisfactory state (> 25 %, but < 50 %), (iii) moderate, which provides a normal state (\leq 10 %, but < 25 %), (iv) absent, an optimal condition is provided (< 10 %).

It is revealed that technologies of winter wheat growing in the conditions of Polissya, Forest-steppe and Steppe Zones of Ukraine can have a negative influence on potassium regime in soils, the influence by intensity can vary from moderate to strong. In Polissya and Forest-steppe, winter wheat growing can lead to deterioration of soil pH status. In Steppe, along with the potassium regime, the technologies can negatively influence soil nitrogen status and the effect may be characterized as strong.

Key words: ecological assessment; growing technology; limiting factors; soil fertility

Pridelava ozimne pšenice v Ukrajini: ekološka ocena tehnologij glede na vplive na rodovitnost tal

Izvleček: Moderne tehnologije pridelave ozimne pšenice je potrebno izboljšati glede na ekološko ovrednotenje njihovega vpliva na indekse rodovitnosti tal. Namen raziskave je bil oceniti tehnologije pridelave ozimne pšenice na različnih tleh in klimatskih razmerah Ukrajine po njihovem vplivu na rodovitnost tal. Ugotovljeno je bilo, da je za oceno ekološke varnosti pridelave poljščin priporočljivo uporabiti metode, ki temeljijo na prepoznavanju negativnih učinkov na rodovitnost tal. Predlagamo naslednje skupine glede na odstopanja od optimalnega stanja: (i) močno odstopanje, ki vodi v nezadovoljive ekološke razmere (> 50 %), (ii) povprečno odstopanje, ki daje zadovoljivo stanje (> 25 %, a manj kot 50 %), (iii) zmerno odstopanje, ki daje normalno stanje (\leq 10 %, a manj kot 25 %), (iv) odstopanja ni, optimalno stanje (< 10 %).

Ugotovljeno je bilo, da lahko imajo tehnologije pridelave ozimne pšenice v razmerah con polesja (Polissya), lesostepe (Forest-steppe) in stepe (Steppe) v Ukrajini negativni vpliv na režim kalija v tleh, jakost vpliva se spreminja od zmerne do močne. V polesju in lesostepi lahko pridelava ozimne pšenice vodi do poslapšanja pH tal. V stepi lahko tehnologije ob vplivu na režim kalija še močno negativno vplivajo na status dušika v tleh.

Ključne besede: ekološko ovrednotenje; tehnologija pridelave; omejujoči dejavniki; rodovitnost tal

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1 INTRODUCTION

At the International Congress on Environmental Issues in Agriculture (Lefebvre et al., 2005) where the most important issues of modern agrotechnologies were discussed, it was stated that their ecological safety is one of the main requirements nowadays. It has been shown by researches (Davidson, 2000; Arshad and Martin, 2002; Tenu et al., 2009; Killebrew and Wolff, 2010; Makarenko and Bondar, 2012) that it is impossible to identify environmental risks and to develop technologies that would meet the modern environmental standards without studying the mechanisms of negative influence of agrotechnical methods of crops growing on ecosystem components (Karlen et al., 2003; Killebrew and Wolff, 2010; Makarenko and Bondar, 2013). Winter wheat - is one of the leading crops for Ukraine. This crop is grown on an area of 6.4 million hectares and occupies about 37-40 % in the structure of crops (according to the Ministry of Agrarian Policy of Ukraine, 2018).

In spite of its role as a major food in Eastern Europe (Petrenko et al., 2017) wheat is growing by technologies that causes environmentally negative impact. Thus, soil tillage, application of pesticides, mineral fertilizers, growth regulators, which can lead to violation of natural processes in the soil system and to soil degradation (Puskás and Farsang, 2009; Killebrew and Wolff, 2010; Mueller et al., 2012).

Baliuk and Medvediev pointed out that soil degradation is a result of maintaining old technologies in Ukrainian agriculture (Baliuk et al., 2012; Ukraine: Soil fertility to strengthen climate resilience. Preliminary assessment of the potential benefits of conservation agri-

culture. 2014). Researches stated that pesticides application leads to soil and terrestrial ecosystems missfunction (Wasim et al., 2009). Application of agrochemicals violating the optimal doses, with expired dates, inappropriate proportions of nutrient elements will - decrease the effective and potential soil fertility, pollute natural water resources by toxicants and reduce the quality of agricultural products (Shang et al., 2019). Taking into account that the vast majority of agrochemicals are recycled products of industrial wastes. For instance, low enriched agro-ores have a high probability of impact on living organisms and ecosystems due to the presence of impurities of heavy metals, radionuclides, organic and inorganic substances (Hazrat et al., 2019). Therefore, the study of the influence of wheat growing technologies on the soil conditions of agroecosystems is of high importance from scientific and practical points of view.

The main purpose of the study was to identify (1) the negative processes in the soils of agroecosystems of different climatic zones of Ukraine for winter wheat cultivation; (2) the implementation of environmental regulation of the effects of winter wheat cultivation technology on the soils in agroecosystems; (3) application of the obtained results for the development of recommendations for winter wheat cultivation in the conditions of Ukraine.

2 MATERIALS AND METHODS

2.1 SITE DESCRIPTION

The research was carried out within the framework of scientific and technical program of National Acade-



Figure 1: Mapping scheme of long-term field experiments location in various soil-climatic zones of Ukraine: 1 - Rivne SARS, 2 - Khmelnytskyi SARS, 3 - Poltava Institute AIP named after M. Vavilov, 4 - SS NULES of Ukraine "Agronomic Research Station", 5 - Zaporizhzhya RS IOS NAAS.

Table 1: Characteristic of technologies of winter wheat growing in different soil-climatic zones of Ukraine

| Parameter | Characteristic of the parameter |
|--|---|
| Poltava Institute AIP named after M. Vavilov | |
| Soil type | chernozem typical low-humus heavy loamy |
| Soil tillage | surface tillage, plowing, pre-sowing cultivation |
| Variety / biological yield | Kosoch / 5.93 t ha ⁻¹ |
| Planting rate / method | 200 kg ha ⁻¹ / conventional sowing |
| Preceding crop | pea |
| Fertilization system | organic fertilizers (manure 10 t ha ⁻¹) and mineral fertilizers N ₅₂ P ₅₂ K ₅₂ |
| Protection system | recommended for this soil-climatic zone |
| Khmelnyskyi SARS | |
| Soil type | chernozem podzolized slightly eroded medium loamy with deep ground-water occurrence |
| Soil tillage | plowing, disking |
| Variety / biological yield | Astet / 6.85 t ha ⁻¹ |
| Planting rate / method | 135 kg ha ⁻¹ / conventional sowing |
| Preceding crop | pea |
| Fertilization system | organic fertilizers (manure 16 t ha ⁻¹ and 8 t ha ⁻¹) and mineral fertilizers (N ₁₁₆ P ₆₀ K ₁₂₀ and N ₅₅ P ₃₀ K ₆₀) |
| Protection system | recommended for this soil-climatic zone |
| SS NULES of Ukraine "Agronomic Research Station" | |
| Soil type | chernozem typical low-humus medium loamy |
| Soil tillage | surface tillage, plowing, pre-sowing cultivation |
| Variety / biological yield | Natsionalna / 6 t ha ⁻¹ |
| Planting rate / method | 150 kg ha ⁻¹ / conventional sowing |
| Preceding crop | pea |
| Fertilization system | mineral fertilizers N ₆₀ P ₆₀ K ₆₀ |
| Protection system | recommended for this soil-climatic zone |
| Rivne SARS | |
| Soil type | dark grey podzolized |
| Soil tillage | surface tillage, plowing, pre-sowing cultivation |
| Variety / biological yield | Poliska 90 / 6.5 t ha ⁻¹ |
| Planting rate / method | 145 kg ha ⁻¹ / conventional sowing |
| Preceding crop | pea |
| Fertilization system | mineral fertilizers N ₉₀ P ₆₀ K ₆₀ , organic (manure 10 t ha ⁻¹), organic-mineral (straw + green manure + N ₉₀ P ₆₀ K ₆₀) |
| Protection system | recommended for this soil-climatic zone |
| Zaporizhzhya RS IOS NAAS | |
| Soil type | chernozem ordinary low-humus |
| Soil tillage | basic cultivation, plowing, pre-sowing cultivation |
| Variety / biological yield | Dalnytska / 7 t ha ⁻¹ |
| Planting rate / method | 200 kg ha ⁻¹ / conventional sowing |
| Preceding crop | black fallow |
| Fertilization system | mineral fertilizers in the following doses: N ₇₅ P ₅₀ K ₂₅ , N ₅₀ P ₅₀ K ₅₀ , N ₁₅ P ₁₀ K ₅ , organic fertilizers: semi-decomposed manure 5.7 t ha ⁻¹ |
| Protection system | recommended for this soil-climatic zone |

my of Agrarian Sciences of Ukraine (NAAS) “Scientific and practical substantiation of sustainable development of agroecosystems in Ukraine”, which envisaged integrated research of crops growing technologies in various soil and climatic zones of Ukraine. The following institutions were involved in this study: Institute of Agroecology and Environmental management of National Academy of Agrarian Sciences (NAAS, 48°18'N, 25°56'E); Rivne State Agricultural Research Station (Rivne SARS, 50°37'N, 26°15'E); Khmelnytskyi State Agricultural Research Station (Khmelnytskyi SARS, 49°25'N, 27°0'E); Poltava Institute of agro-industrial production (Poltava Institute AIP, 49°35'N, 34°34'E) named after M. Vavilov; Zaporizhzhya Agricultural Research Station of the Institute of Oilseeds (Zaporizhzhya RS IOS NAAS, 47°50'N, 35°10'E); Separated subdivision of National University of Life and Environmental Sciences of Ukraine (SS NULES of Ukraine, 50°10'N, 30°19'E) “Agronomic Research Station”. The research was conducted during 2007 - 2018 years in the conditions of long-term field experiments (established more than 20 years ago) located in Polissya, Forest-Steppe and Steppe regions of Ukraine (Figure 1).

2.2 METHODOLOGY OF TECHNOLOGIES ASSESSMENT

The basic technology (BT) of winter wheat growing which envisaged soil tillage depending on its type, selection of regional variety, seed rates and method of sowing, system of plant protection. In addition, technologies with application of mineral and organic fertilizers in various combinations were studied, taking into account soil-climatic conditions of the of the experiments location (Table 1).

The basic agrochemical parameters of the soil were determined according to standardized methods: pH_{KCl} - by potentiometric method (displacement of exchange ions H^+ and Al^{3+} 1N KCl ($pH = 5.56$) ratio of soil to solution was 1 : 2.5), nitrogen content that is easily hydrolysed - by Cornflind (the method is based on alkaline hydrolysis of organic nitrogen-containing compounds of soil under the action of 1N NaOH for two days at 260 °C. The released ammonia is absorbed by boric acid and is determined by titration with sulfuric acid), content of exchangeable potassium and labile phosphorus - according to the modified Machigin method (the method is based on the removal of mobile compounds of phosphorus and potassium from the soil with a 1 % $((NH_4)_2 CO_3)$, ($pH 9.0$) at the soil:solution ratio 1 : 20 and a temperature of 25 ± 2 ° C. The soil suspension was shaken for - 5 minutes and than, insulating the soil

in solution - 20 hours. Before determining the phosphorus, the colored soil extraction was discolored with activated carbon. Phosphorus was determined calorimetrically after ammonium molybdate addition. Potassium was determined by flame photometry. Soil organic matter (SOM) was determined - by Tyurin method (the method is based on the oxidation of organic carbon to CO_2 by a solution of potassium bichromate and sulfuric acid, the excess of which is titrated with Mora salt).

2.3 STATISTICAL ANALYSIS

Data are presented as mean values of four replicates and standard deviations. The significance of the experimental data was estimated by the analysis of variance (two-factor ANOVA) following calculation of the least significant difference LSD_{05} .

3 RESULTS AND DISCUSSION

Following the concept of limiting factors, a method for evaluating the technology was proposed the intensity of its negative influence on soil fertility indices:

strong influence, which leads to an unsatisfactory ecological state of components of agroecosystems or individual processes that occur in them (the deviation from the optimum in the direction of deterioration is more than 50 %);

medium influence that provides a satisfactory state of components of agroecosystems or individual processes that occur in them (the deviation from the optimum in the direction of deterioration is greater than 25 % but does not exceed 50 %);

moderate influence, which ensures a normal state of components of agroecosystems or individual processes that occur in them (the deviation from optimum in the direction of deterioration more than 10 % but not exceeding 25 %);

no influence, which ensures an optimal state of components of agroecosystems or individual processes that occur in them (the deviation from the optimum in the direction of deterioration does not exceed 10 %) is provided.

The optimal soil parameters by fertility indices were determined according to DSTU 4362: 2004 “Soil quality. Soil fertility indices”. The optimal parameters of fertility indexes are presented in Table 2.

According to the results of our research, the technologies of winter wheat growing in different soil and climatic conditions of Ukraine influenced the formation of edaphic soil parameters of the agroecosystem,

Table 2: The range of soil parameters and respective ecological state

| Ecological state | Nitrogen that is easily hydrolyzed | Labile phosphorus | Exchangeable potassium | pH _{KCl} | SOM, % |
|---|------------------------------------|-------------------|------------------------|-------------------|---------|
| mg kg ⁻¹ | | | | | |
| chernozem typical low-humus heavy loamy | | | | | |
| Standard | 35–45 | 45–60 | 300–400 | 6.3–7.0 | 4.5–5.7 |
| Optimal | 32–34 | 41–44 | 270–299 | 5.7–6.2 | 4.1–4.4 |
| Normal | 27–33 | 34–43 | 228–269 | 4.8–5.6 | 3.4–4.0 |
| Satisfactory | 18–26 | 23–33 | 150–227 | 3.2–4.7 | 2.3–3.3 |
| Unsatisfactory | < 18 | < 23 | < 150 | < 3.2 | < 2.3 |
| chernozem podzolized medium loamy slightly eroded | | | | | |
| Standard | 35–45 | 150–200 | 120–170 | 5.7–6.4 | 2.8–4.2 |
| Optimal | 34–32 | 135–149 | 108–119 | 5.1–5.6 | 2.5–2.7 |
| Normal | 33–27 | 113–134 | 90–107 | 4.3–5.5 | 2.1–2.4 |
| Satisfactory | 18–26 | 75–112 | 59–89 | 2.9–4.4 | 1.3–2.0 |
| Unsatisfactory | < 18 | < 75 | < 60 | < 2.9 | < 1.4 |
| chernozem typical low-humus medium loamy | | | | | |
| Standard | 35–45 | 45–60 | 300–400 | 6.0–6.8 | 3.5–5.0 |
| Optimal | 34–32 | 41–44 | 270–299 | 5.4–5.9 | 3.2–3.4 |
| Normal | 33–27 | 34–40 | 228–269 | 4.5–5.3 | 2.6–3.1 |
| Satisfactory | 18–26 | 22–33 | 150–227 | 3.0–4.4 | 1.8–2.5 |
| Unsatisfactory | < 18 | < 23 | < 150 | < 3.0 | < 1.8 |
| dark grey podzolized | | | | | |
| Standard | 35–45 | 150–200 | 170–220 | 5.3–6.0 | 1.6–2.6 |
| Optimal | 34–32 | 135–149 | 153–169 | 4.8–5.2 | 1.4–1.5 |
| Normal | 33–27 | 113–134 | 128–152 | 4.0–4.7 | 1.2–1.3 |
| Satisfactory | 18–26 | 75–112 | 85–127 | 2.7–3.9 | 0.8–1.1 |
| Unsatisfactory | < 18 | < 75 | < 85 | < 2.7 | < 0.8 |
| chernozem ordinary low-humus | | | | | |
| Standard | 35–45 | 45–60 | 300–400 | 6.8–7.6 | 3.2–5.3 |
| Optimal | 34–32 | 41–44 | 270–299 | 6.1–6.7 | 2.9–3.1 |
| Normal | 33–27 | 34–43 | 228–269 | 5.1–6.0 | 2.4–2.8 |
| Satisfactory | 18–26 | 23–33 | 150–227 | 3.4–5.0 | 1.6–2.3 |
| Unsatisfactory | < 18 | < 23 | < 150 | < 3.4 | < 1.6 |

and, consequently, the conditions of plant nutrition. The soil fertility indicators by long-term influence of the winter wheat growing technologies are presented in Table 3.

A comparison of the soil actual parameters with the optimum level allowed to establish general patterns of changes occurring in the soil component of agroecosystems, and to identify the main negative effects of technologies (Table 4):

nitrogen regime: there was no negative influence of the technologies on the content of nitrogen forms in

typical, podzolized and dark gray podzolized soils. The exception was chernozem, in which the technology led to the decrease of nitrogen content. The effect varied from medium to strong. Negative phenomenon was not eliminated even with nitrogen application at the rates $N_{15} - N_{75}$ kg ha⁻¹;

phosphorus regime: the technologies provided optimal soil parameters by the content of phosphorus form in all soils. The exception was observed in chernozem podzolized, where the basic technology implementation led to the depletion of mobile phosphorus

Table 3: Indicators of soil fertility for different technologies of winter wheat growing

| Technology | Indicators of soil fertility | | | | |
|---|---|-------------------|------------------------|-------------------|------------|
| | Nitrogen that is easily hydrolyzed | Labile phosphorus | Exchangeable potassium | pH _{KCl} | SOM, % |
| | mg kg ⁻¹ | | | | |
| | chernozem typical low-humus heavy loamy | | | | |
| BT | 102 ± 1.70 | 78 ± 3.40 | 65 ± 1.63 | 4.8 ± 0.09 | 5.4 ± 0.16 |
| BT + manure 10 t ha ⁻¹ | 109 ± 2.49 | 92 ± 0.94 | 103 ± 1.41 | 5.0 ± 0.09 | 5.5 ± 0.22 |
| BT + N ₅₂ P ₅₂ K ₅₂ + straw + N ₁₀ | 112 ± 1.25 | 132 ± 2.83 | 112 ± 0.82 | 5.5 ± 0.21 | 5.3 ± 0.05 |
| BT + manure 10 t ha ⁻¹ + N ₅₂ P ₅₂ K ₅₂ | 119 ± 0.94 | 170 ± 2.62 | 153 ± 3.09 | 5.2 ± 0.09 | 5.5 ± 0.05 |
| LSD _{0.05} | 12.11 | 3.37 | 6.67 | 0.18 | 0.21 |
| | chernozem podzolized medium loamy slightly eroded | | | | |
| BT | 101.5 ± 0.26 | 78 ± 0.47 | 72 ± 0.94 | 5.0 ± 0.05 | 3.1 ± 0.05 |
| BT + N ₁₁₆ P ₆₀ K ₁₂₀ | 119.0 ± 1.89 | 146 ± 0.94 | 106 ± 0.29 | 3.5 ± 0.03 | 5.0 ± 0.22 |
| BT + manure 16 t ha ⁻¹ | 105.6 ± 0.19 | 246 ± 2.83 | 235 ± 0.31 | 3.8 ± 0.09 | 6.3 ± 0.16 |
| BT + manure 8 t ha ⁻¹ + N ₅₅ P ₃₀ K ₆₀ | 103.3 ± 0.14 | 490 ± 0.47 | 160 ± 0.12 | 3.5 ± 0.05 | 6.4 ± 0.09 |
| LSD _{0.05} | 22.12 | 14.05 | 17.23 | 0.86 | 1.16 |
| | chernozem typical low-humus medium loamy | | | | |
| BT | 84.2 ± 0.08 | 67 ± 0.38 | 230 ± 0.45 | 7.7 ± 0.02 | 2.9 ± 0.05 |
| BT + N ₆₀ P ₆₀ K ₆₀ | 94.5 ± 0.37 | 62 ± 0.05 | 240 ± 0.37 | 7.7 ± 0.03 | 3.2 ± 0.09 |
| LSD _{0.05} | 4.67 | 1.16 | 8.04 | 0.14 | 0.57 |
| | dark grey podzolized | | | | |
| BT | 75.4 ± 0.05 | 165 ± 0.12 | 53 ± 0.16 | 4.9 ± 0.09 | 1.3 ± 0.02 |
| BT + N ₉₀ P ₆₀ K ₆₀ | 87.5 ± 0.16 | 245 ± 0.14 | 65 ± 0.21 | 5.2 ± 0.05 | 1.5 ± 0.04 |
| BT + manure 10 t ha ⁻¹ | 91.0 ± 0.17 | 295 ± 0.08 | 85 ± 0.19 | 5.1 ± 0.16 | 1.5 ± 0.05 |
| BT + N ₉₀ P ₆₀ K ₆₀ + straw + green manures | 91.0 ± 0.16 | 340 ± 0.09 | 91 ± 0.26 | 5.6 ± 0.16 | 1.4 ± 0.05 |
| LSD _{0.05} | 2.96 | 15.11 | 6.12 | 0.92 | 0.58 |
| | chernozem ordinary low-humus | | | | |
| BT | 9.8 ± 0.09 | 100 ± 0.41 | 150 ± 0.16 | 7.15 ± 0.16 | 3.9 ± 0.02 |
| BT + N ₇₅ P ₅₀ K ₂₅ | 15.6 ± 0.34 | 243 ± 0.17 | 183 ± 0.17 | 7.00 ± 0.05 | 4.1 ± 0.05 |
| BT + N ₅₀ P ₅₀ K ₅₀ | 22.3 ± 0.17 | 280 ± 0.19 | 205 ± 0.21 | 6.72 ± 0.09 | 3.8 ± 0.02 |
| BT + N ₁₅ P ₁₀ K ₅ | 14.7 ± 0.08 | 199 ± 0.47 | 159 ± 0.37 | 6.98 ± 0.16 | 4.1 ± 0.09 |
| BT + manure 5.7 t ha ⁻¹ | 11.4 ± 0.19 | 144 ± 0.19 | 219 ± 0.19 | 7.07 ± 0.08 | 3.8 ± 0.05 |
| LSD _{0.05} | 3.82 | 22.14 | 20.10 | 3.57 | 2.63 |

level and the influence of technology was characterized as strong;

potassium regime: there was a negative influence of the technologies on the content of exchangeable forms of potassium in all soil types, it varied from moderate to strong. The most dangerous impact of the technologies was recorded in dark gray podzolized soils (strong);

soil pH: the influence of technologies within the limits of the moderate and average in chernozem

typical low-humus heavy-loamy and chernozem podzolized; in dark gray podzolized soil, the negative influence was observed only in the basic technology;

SOM content: technologies did not lead to negative changes in the SOM. The obtained results indicate the inappropriateness of using SOM status indicator as a diagnostic tool for assessing the influence of technologies on soil fertility.

Thus, it was established that in Polissya, Forest-steppe and Steppe of Ukraine the technologies of win-

Table 4: Influence of the winter wheat growing technologies on soil fertility indicators

| Technology | Negative influence of technology on indicators of soil condition | | | | |
|---|--|-------------------|------------------------|-------------------|----------|
| | Nitrogen that is easily hydrolyzed | Labile phosphorus | Exchangeable potassium | pH _{KCl} | SOM, % |
| chernozem typical low-humus heavy loamy | | | | | |
| BT | absent | absent | strong | moderate | absent |
| BT + manure 10 t ha ⁻¹ | absent | absent | strong | moderate | absent |
| BT + N ₅₂ P ₅₂ K ₅₂ + straw + N ₁₀ | absent | absent | strong | moderate | absent |
| BT + manure 10 t ha ⁻¹ + N ₅₂ P ₅₂ K ₅₂ | absent | absent | strong | moderate | absent |
| chernozem podzolized medium loamy slightly eroded | | | | | |
| BT | absent | strong | strong | moderate | absent |
| BT + N ₁₁₆ P ₆₀ K ₁₂₀ | absent | absent | moderate | medium | absent |
| BT + manure 16 t ha ⁻¹ | absent | absent | absent | medium | absent |
| BT + manure 8 t ha ⁻¹ + N ₅₅ P ₃₀ K ₆₀ | absent | absent | absent | medium | absent |
| chernozem typical low-humus medium loamy | | | | | |
| BT | absent | absent | moderate | absent | moderate |
| BT + N ₆₀ P ₆₀ K ₆₀ | absent | absent | moderate | absent | absent |
| dark grey podzolized | | | | | |
| BT | absent | absent | strong | moderate | moderate |
| BT + N ₉₀ P ₆₀ K ₆₀ | absent | absent | strong | absent | absent |
| BT + manure 10 t ha ⁻¹ | absent | absent | strong | absent | absent |
| BT + N ₉₀ P ₆₀ K ₆₀ + straw + green manures | absent | absent | strong | absent | absent |
| chernozem ordinary low-humus | | | | | |
| BT | strong | absent | medium | absent | moderate |
| BT + N ₇₅ P ₅₀ K ₂₅ | strong | absent | medium | absent | absent |
| BT + N ₅₀ P ₅₀ K ₅₀ | medium | absent | medium | absent | moderate |
| BT + N ₁₅ P ₁₀ K ₅ | strong | absent | medium | absent | absent |
| BT + manure 5.7 t ha ⁻¹ | strong | absent | medium | absent | moderate |

ter wheat growing negatively affected potassium regime of soils: - there was a depletion of mobile potassium forms; in chernozem typical low-humus and chernozem podzolized medium-loamy winter wheat growing led to deterioration of the acid-base conditions of the soil - there were processes of acidification of the soil solution. In Steppe, along with potassium regime, the technology negatively affected nitrogen regime of the soil - there were observed processes of depletion of stocks of nitrogen compounds. It is possible to predict that the indicated negative phenomena in the soil led to a violation of the interconnections in the soil-plant system. To confirm this, the productivity of winter wheat cultivation under various technologies was investigated.

It is known that productivity, that is the ability of ecosystem to form biomass over a certain period of time on a certain area, is an integral indicator of its state. In agroecosystems, it was decided to determine productiv-

ity of a main agricultural crop (a determinant). In our case, the determinant was winter wheat and, according to the level of its productivity, an assessment of the impact of technology on the agroecosystem was carried out. Potential productivity of a certain wheat variety was taken as a standard (etalon) since this indicator indicates the maximum possible biological potential the crop can use for the formation of biomass.

At the same time, in case of reduced wheat productivity relative to the standard, the limiting edaphic soil factors, that could negatively affect plant growth and development, were determined. In Forest-steppe zone based on Poltava Institute AIP named after M. Vavilov winter wheat of the Kosoch variety was studied. The potential yield of this variety is 5.93 t ha⁻¹. Climate of Poltava region is continental. The mean annual temperature is +8.2 °C. The mean annual precipitation is 580-480 mm. The productivity of wheat at the po-

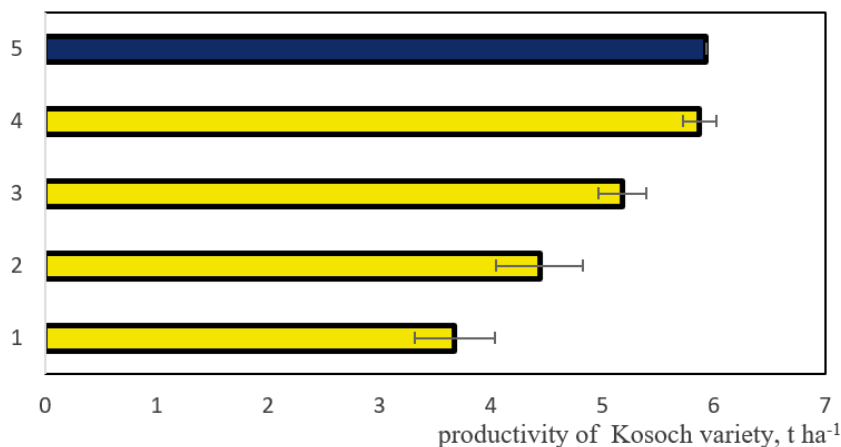


Figure 2: Influence of the technologies on productivity of winter wheat variety Kosoch (soil - chernozem typical low-humus heavy-loamy; 1. BT; 2. BT + manure 10 t ha⁻¹; 3. BT + N₅₂P₅₂K₅₂ + straw + N₁₀; 4. BT + manure 10 t ha⁻¹ + N₅₂P₅₂K₅₂; 5. Standard)

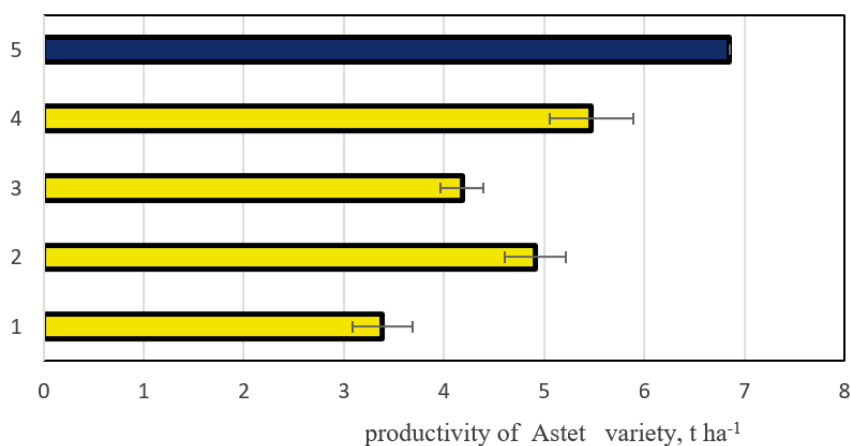


Figure 3: Influence of the technologies on productivity of winter wheat variety Astet (soil - chernozem podzolized medium loamy slightly eroded; 1. BT; 2. BT + N₁₁₆P₆₀K₁₂₀; 3. BT + manure 16 t ha⁻¹; 4. BT + manure 8 t ha⁻¹ + N₅₅P₃₀K₆₀; 5. Standard)

tential level was ensured by the technology with integrated mineral and organic fertilizer application (BT + N₅₂P₅₂K₅₂ + manure of 10 t ha⁻¹). The basic technology, the technology with applied organic fertilizers did not allow achieving the standard level of crop productivity. The deviation from the standard was 26.4-35.5 %, that is, the negative impact of technology is estimated as medium (Figure 2). It can be assumed that one of the reasons for unsatisfactory growth and development of plants using these technologies was insufficient level of mobile potassium supply to plants. This effect was amplified by the discrepancy of the reaction of the soil environment with requirements of the crop.

In the conditions of Khmelnytskyi SARS (Forest-Steppe zone), winter wheat of the Astet variety was studied, whose potential yield is 6.85 t ha⁻¹. Climate of Khmelnytsky region is continental. The mean annual

temperature is + 7.3°C. The mean annual precipitation is 530-670 mm. The basic technology, as well as the technologies of mineral fertilizers BT + N₁₁₆P₆₀K₁₂₀, BT + manure of 16 t ha⁻¹ application did not provide the optimal conditions for plant growth and development. The productivity level of wheat was 27.3-52.8 % lower comparing the standard. The influence of the technologies on the state of agroecosystem by the level of wheat productivity can be estimated as strong and average (Figure 3). One of the reasons for this phenomenon could be the depletion of the mobile forms of soil phosphorus, potassium and the discrepancy of soil pH to requirements of the crop.

In the conditions of SS NULES of Ukraine "Agro-nomic Research Station" (Forest-Steppe zone) winter wheat of the Natsionalna variety was studied, the potential yield of which is 6 t ha⁻¹. Climate of Kyiv re-

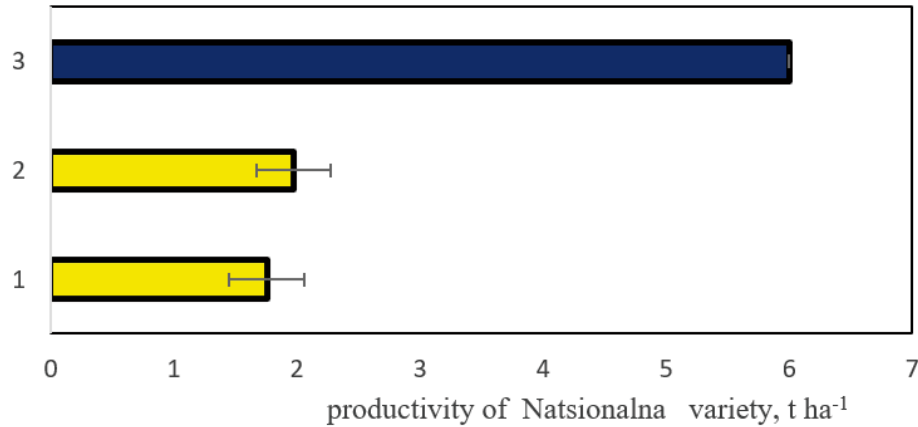


Figure 4: Influence of the technologies on productivity of winter wheat variety Natsionalna (soil - chernozem typical low-humus medium loamy; 1. BT; 2. BT + N₆₀P₆₀K₆₀; 3. Standard) (Note: Averages in groups are significantly different from each other, ANOVA with Bonferroni correction, except of those, marked by * $p < 0.05$)

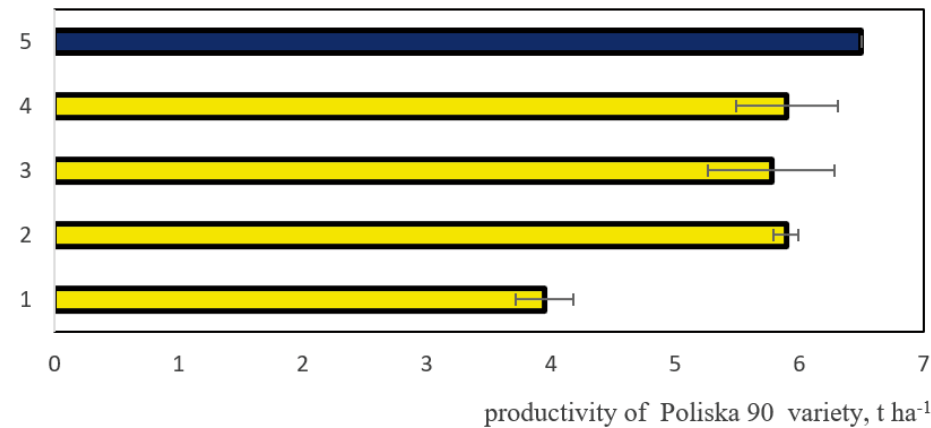


Figure 5: Influence of the technologies on productivity of winter wheat variety Poliska 90 (soil - dark grey podzolized; 1. BT; 2. BT + N₉₀P₆₀K₆₀; 3*. BT + manure 10 t ha⁻¹; 4*. BT + N₉₀P₆₀K₆₀ + straw + green manure; 5. Standard) (Note: Averages in groups are significantly different from each other, ANOVA with Bonferroni correction, except of those, marked by * $p < 0.05$)

gion is continental. The mean annual temperature is + 10.3 °C. The mean annual precipitation is 500-600 mm. The basic technology and the technology that envisaged mineral fertilizers application at the rate N₆₀P₆₀K₆₀ did not ensure the implementation of biopotential of the variety. The reduction of wheat productivity in relation to the standard was 62.3-65.2 %. Consequently, the influence of the technology on the state of agroecosystem by wheat productivity can be estimated as strong (Figure 4). One of the reasons could be an insufficient level of plant's supply with mobile potassium forms.

In Polissya zone, based on Rivne SARS, winter wheat of the Poliska 90 variety was studied. According to the characteristics of the variety, the potential yield of this variety is 6.5 t ha⁻¹. Climate of Rivne region is

continental. The mean annual temperature is + 7.8 °C. The mean annual precipitation is 600-700 mm. The actual yield level was close to the potential and achieved with the technology included mineral fertilizers application in combination with straw and green manure (N₉₀P₆₀K₆₀ + straw + green manure). The basic technology, as well as technologies that envisaged application of mineral and organic fertilizers separately, did not ensure the implementation of the variety biopotential. The deviation from the standard was 10.6-37.2 %, the impact of technology on the agroecosystem state was moderate and average (Figure 5). It can be assumed that one of the reasons was insufficient level of plant provision with mobile potassium forms.

In Steppe zone, in the conditions of Zaporizhzhya

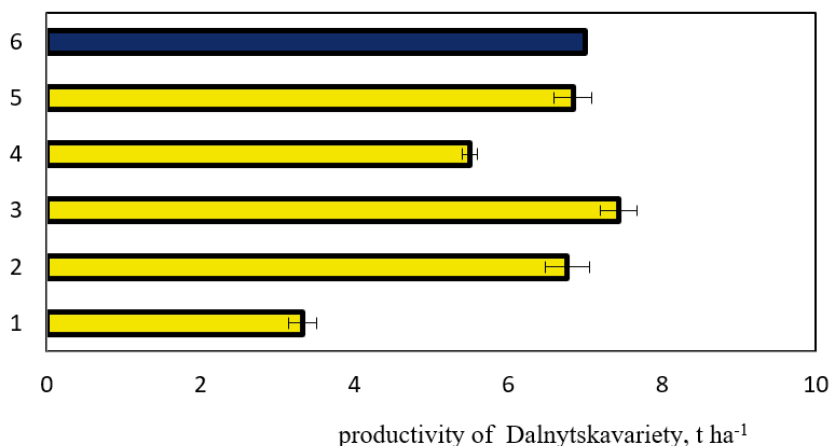


Figure 6: Influence of the technologies on productivity of winter wheat variety Dalnytska (soil – chernozem ordinary low-humus; 1. BT; 2. BT + N₇₅P₅₀K₂₅; 3. BT + N₅₀P₅₀K₅₀; 4. BT + N₁₅P₁₀K₅; 5. BT + manure 5.7 t ha⁻¹; 6. Standard)

RS IOS NAAS winter wheat of the Dalnytska variety was studied. According to characteristics of the variety, the potential yield is 7 t ha⁻¹. Climate of Zaporizhzhia region is continental. The mean annual temperature is +12.8 °C. The mean annual precipitation is 430-475 mm. The technology with mineral fertilizers application provided optimum conditions for the growth and development of plants - wheat productivity exceeded the standard and amounted to 7.56 t ha⁻¹. Despite the fact that the average negative impact of this technology on nitrogen and potassium regimes of chernozem was noted, plant nutrition was balanced. At the same time, other combinations of fertilizers led to strong negative influence of the technologies on nitrogen regime of the soil and average influence on potassium regime. Consequently, the influence of these technologies can be estimated as strong and moderate according to wheat productivity (Figure 6).

Thus, it has been established that modern technologies of winter wheat growing, in most cases, do not provide plants with balanced mineral nutrition, which may be reason for the decreasing crop productivity if compared to its biological potential.

4 CONCLUSIONS

We recommend using a method based on identifying negative impacts of crop growing technologies on soil fertility in order to estimate ecological safety. Negative impacts of deviations from the optimum to the direction of deterioration are proposed to be grouped as follows: strong, which leads to an unsatisfactory ecological condition (> 50 %), average that provides a satisfactory state (> 25 %, but < 50 %), moderate, which

provides a normal state (≤10 %, but < 25 %), absent, an optimal condition is provided (< 10 %).

It is revealed that technologies of winter wheat growing in Polissya, Forest-steppe and Steppe Zones of Ukraine can have a negative influence on potassium regime of soils; the influence by intensity can vary from moderate to strong. In Polissya and Forest-steppe, technologies of winter wheat growing can lead to deterioration of soil pH status. In the conditions of Steppe, along with potassium regime, the technologies can negatively influence nitrogen status and the effect may be characterized as strong.

It is shown that modern technologies of winter wheat growing, in most cases, do not provide plants with balanced nutrition, which may be one of the reasons for the low level of productivity of the crop relative to the biological potential of the variety. The decrease in productivity can fluctuate within 10.6-73.6 %.

Modern technologies of winter wheat growing need to be improved and revised taking into account the results of ecological evaluation of their impact on soil fertility indices.

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