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Diagnosis of the functional state of transformed acid soils agroecosystems depending on long-term anthropogenic loads

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Abstract. The main priority of agro-industrial production has always been and remains to provide the global population and its yearly increments with food. The issue of soil fertility improvement is still the most important task of agricultural science. The assessment of the agroecological condition of Albic Stagnic Luvisol using carbon dioxide emission, redox potential, and biotic activity was carried out, based on modern methodological approaches, such as soil quality evaluation via ecologically-related biological parameters. Carbone dioxide emission, redox, and biological processes in long-term stationary experiment depend on the degree of soil acidity reduction. Soil acidification can be minimized through chemical melioration with the combined application of different doses of mineral fertilizers and manure. It was found that carbon dioxide emission is optimal in an organo-mineral fertilizing system with application of 10 t of manure per 1 ha and $N_{65}P_{68}K_{68}$ with lime dose (2.5 t ha^{-1}) calculated according to pH buffering capacity. It is due to oxidative and moderately oxidative conditions created. This organo-mineral fertilizing system also increases the number of aerobic bacteria and overall biological activity. The mineral fertilization and the use of Albic Stagnic Luvisol without fertilizers are accompanied by increased mineralization, growth of reductive processes, and the number of moulds. Studies have shown that it is advisable to include CO_2 emission, redox potential and biological activity along with physicochemical and agrochemical soil properties to assess the influence of different anthropogenic loads on soil formation.

Key words: acidity, Albic Stagnic Luvisol, CO_2 emission, fertilizers, liming, redox potential, microbiological activity.

Used abbreviations: Eh: soil redox potential; rH2: Clark's index; CFU: colony-forming unit; n: norm; HA: humic acids; FA: fulvic acids; NAAS: National Academy of Agrarian Sciences of Ukraine.

INTRODUCTION

Solving the problem of food security and providing the global population and its yearly increments with food has always been and remains the main priority of agro-industrial production (Parikh & James, 2012; Yemets, 2012; Calicioglu, 2019). So, the issue of soil fertility improvement is one of the most important tasks of agricultural science (Havlin & Heiniger, 2020). Studies aimed at preserving and maintaining the stability of ecosystems and their components are especially relevant due to the current climate change and intense anthropogenic impact.

Precision agriculture is crucial to the formation of a profitable and high-quality harvest through continuous monitoring of the basic functions of soils, timely correction and implementation of individual components of agricultural technologies. The natural potential fertility of Albic Stagnic Luvisol (WRB, 2015) in Ukrainian Western Forest-Steppe is only 1.2–1.4 t ha^{-1} of grain units due to high acidity and low nutrient content. Though its acidity is genetically inherited, an efficient system of fertilizers and agro-melioration can prevent its further acidification. Nowadays soil acidification on a global scale leads to deterioration of agro-ecological status and loss of fertility - the main function of soils (Tian & Niu, 2015; Goulding, 2016; Neina, 2019).

Diagnosis of fertility elements through soil testing and optimization of their condition is a key principle for the balanced use of acidic soils. Fertility elements are defined as elementary material carriers of soil regimes that are involved in the biological cycle and directly affect plant growth and development (Truskavetskyi et al., 2020).

It should be noted that in recent years the average global concentration of greenhouse gases in the atmosphere, including carbon dioxide, is increasing due to significant climate change (Green et al., 2019). Carbone dioxide flows from the soil into the atmosphere depend primarily on the processes that occur in the soil under the influence of various anthropogenic factors during land use, such as disturbance of soil aggregates (Ontl & Schulte, 2012). The imbalance of soil carbon cycles leads to the loss of both organic matter, essential available nutrients and additional entry of greenhouse gases into the atmosphere, which further intensifies the global warming effects (Popirnyi et al., 2020).

Therefore, a clear account of the $C\text{-}CO_2$ flow to the atmosphere is necessary for assessing peculiarities of carbon dioxide production by soils. It is also important to identify trends in soil properties changes (Trofymenko et al., 2019). The values of CO_2 emission together with soil ability to sequester it are an important component of sustainable land use in the context of climate change.

The quantitative characteristics of the processes occurring in the soil environment, their direction and their intensity are reflected in the redox potential. However, the absolute values of the redox potential do not always adequately represent redox conditions created in different agroecosystems, as the intensity of the redox potentials is significantly affected by the reaction of the environment. Soil redox potential (Eh) and pH are the main parameters of plant growth that determine soil fertility (Kanwar, 2015; Cottes et al., 2020). The relationship between them is reflected by Clark's index (rH_2): $rH_2 = \frac{Eh}{30} + 2\,pH$ (Mamontov et al., 2006).

Redox potential is the most readily available indicator of the soil redox system. It covers the entire range in which the various inorganic redox systems operate (Yu & Rinklebe, 2013). The redox potential of aerobic soils, which are mostly cultivated, is given little attention. Although this important parameter cannot be ignored, as the transformation of plant residues, rate of organic substances accumulation and composition are closely related to Eh. The redox processes are also associated with the conversion of nitrogen compounds, phosphorus, sulphur, iron, manganese in soils (Kyrylchuk & Bonishko, 2011).

An important diagnostic indicator that objectively assesses the state of edaphic comfort is the biological activity of the soil (El-Ramady et al., 2014). The living part of the soil not only provides the mineralization and immobilization mechanism of organic matter but also performs several global regulatory functions in the formation of soil fertility. Therefore, due to the high lability, microorganisms are sensitive to transformations that occur in the soil during its agricultural use and can serve as environmental indicators of these changes (Symochko et al., 2017).

Redox potential and pH of the soil largely determine the types of metabolism that occur in the bacterial community in the early stages of development, and therefore are important parameters of biological activity and affect the development of microorganisms (Husson, 2013).

Such studies are especially relevant for Albic Stagnic Luvisol, which occupy large areas in Europe and Ukrainian Western Forest-Steppe zone in particular. They are characterized by the high acidity of the soil solution and low fertility. Due to climate change, the problem of environmentally friendly use of acidic soils has become much more acute. Systematic management of soil fertility makes it possible to normalize anthropogenic loads harmonizing soil productive functions with ecological ones (Truskavetskyi & Tsapko, 2016).

Obtaining objective information about the state and changes of the agroecosystems, their components under the influence of various agrogenic factors is possible only in stationary experiments. In this regard the results of the impact assessment of long-term agricultural loads with different doses and ratios of fertilizers, manure and lime in a long-term stationary experiment are noteworthy.

Our research aimed to evaluate the impact of long-term application of various fertilizing systems and periodic liming on the agro-ecological condition of the soil using informative diagnostic indicators of carbon dioxide emission, redox potential and biological activity for effective management of Albic Stagnic Luvisol fertility.

MATERIALS AND METHODS

Research work was performed during IX crop rotation in the classical stationary experiment (49°47'54.3"N 23°52'26.9"E) of the Laboratory of Agricultural Chemistry (Institute of Agriculture of the Carpathian region NAAS), established in 1965 and registered as a long-term agricultural field experiment of NAAS (NAAS registration certificate No. 29).

The long-term experiment is placed on three fields, each has 18 variants in triplicate. The location of the variants is single-tiered, equential. The total plot area is 168 m^2, accounting - 100 m^2. Crop rotation is four-field with the following crops: corn for silage - spring barley with the sowing of meadow clover – meadow clover – winter wheat. Agricultural cultivation techniques, tillage and crop care are standard for the Ukrainian Western Forest-Steppe zone.

The agrochemical characteristics of the arable layer of Albic Stagnic Luvisol before the experiment start were as follows: humus content (according to Tyurin) 1.42%, pH_{KCl} 4.2, hydrolytic acidity (according to Kappen) 4.5, exchangeable acidity (according to Sokolov) - 0.6 mg-eq 100 g^{-1} of soil, the content of mobile aluminium 60.0, mobile phosphorus (according to Kirsanov) and exchangeable potassium (according to Maslova) - 36.0 and 50.0 mg kg^{-1} of soil respectively.

After 50 years of soil use, these values in control variant without fertilizers have not undergone significant changes: humus content is 1.48%, pH_{KCl} 4.3, hydrolytic acidity 4.5 mg-eq 100 g^{-1} of soil, the content of mobile aluminium 60.7, mobile phosphorus and exchangeable potassium (according to Kirsanov) are 36.5 and 46.3 mg kg^{-1} of soil respectively. Different fertilizer systems led to significantly opposite changes in soil properties. Optimal organo-mineral fertilizer system with liming led to lowering of hydrolytic acidity up to 2.28 mg-eq 100 g^{-1}, mobile aluminium content - 4.20 mg kg^{-1} and increasing humus content to 1.93%, pH_{KCl} 5.38, mobile phosphorus and exchangeable potassium to 188.6 and 190.4 mg kg^{-1} of soil respectively. Mineral fertilizer systems caused much lower humus content (1.59%), pH_{KCl} 4.12, an increase of hydrolytic acidity to 4.69 mg-eq 100 g^{-1}, mobile aluminium to 75,0, mobile phosphorus and exchangeable potassium to 167.5 and 128.8 mg/kg, respectively.

Semi-overripe cattle manure with straw bedding, ammonium nitrate (34.5%), granular superphosphate (19.5%), potassium salt (40%), nitroammophos (NPK 16%) was used in the experiment. When using nitroammophos, NPK content was balanced with simple fertilizers. Manure (40–60 t ha^{-1}) was applied before corn crops. Phosphorus-potassium fertilizers were applied in autumn, and nitrogen fertilizers - before pre-sowing cultivation. Liming according to the scheme was performed before the ninth crop rotation. Limestone flour (93.5% $CaCO_3$) was used as limestone material. Starting from the VIII rotation the second mow of meadow clover was ploughed as an organic fertilizer in all variants of the experiment.

Carbon dioxide emission was studied in 2016–2018 in the phases of spring tillering (BBCH26), stem elongation (BBCH31-33), and full ripeness (BBCH89) during winter wheat vegetation. It ends the ninth crop rotation. CO_2 measurements were carried out in plots with different fertilizer system. The experimental factors were: liming, organic and mineral fertilizers. The variants included:

- control (without fertilizer, var. 1);
- organo-mineral fertilizing system (10 t of manure per ha of crop rotation area + $N_{65}P_{68}K_{68}$) with periodic liming by 1.0 n of $CaCO_3$ (6.0 t of limestone flour per ha) according to hydrolytic acidity (var. 7);
- the same fertilizing system with an optimal dose of lime (2.5 t ha^{-1}), calculated according to acid-base buffering capacity (var. 8);
- mineral fertilizing system ($N_{105}P_{101}K_{101}$) with liming by 1.5 n of $CaCO_3$ (9.0 t ha^{-1}) according to hydrolytic acidity (var. 17);
- the same fertilizing system with applying $CaCO_3$ (2.5 t ha^{-1}) according to acid-base buffering capacity (var. 18);
- mineral fertilizing system ($N_{65}P_{68}K_{68}$, var. 15).

CO_2 measurements from soil surface were made in the field on a two-channel infrared gas analyser CO_2-meter ‘K-30 Probe’ and related software (DAS 100) using standard procedures (Pumpanen et al., 2004). Measurements were performed 3–5 times a day followed by a determination of the average value.

The redox potential was measured with a pH-150MA millivoltmeter following DSTU ISO 11271:2004.

Soil samples from the arable layer of Albic Stagnic Luvisol (0–25 cm) were prepared by DSTU ISO 11464-2001 after winter wheat harvesting. Laboratory and analytical studies were performed in a certified agrochemical laboratory of the Institute of ACR NAAS. The pH_{KCl} determination was performed by potentiometric method at 1:2.5 soil:KCl ratio using a pH meter 'pH-301' and glass electrodes (DSTU ISO 10390:2007). The population of microorganisms of the main ecological and trophic groups was enumerated by culturing selected soil samples (soil suspension) on special growth media (agar, Endo and Sabouraud). Viable plate count was conducted in 21 days depending on the growth rate and physiological characteristics of the group. Proteolytic and total biological activity of the soil was determined by application method according to the intensity of decomposition of the gelatine layer of X-ray film and linen cloth respectively. The films were buried for 30 days in the upper fertile layer of soil (0–25 cm) in triplicate. After digging out and drying, the degree of decomposition of the fabric and the gelatine layer was determined as a percentage.

Climatic conditions during the 2016–2018 years of research had their peculiarities. The average temperature was higher compared to the long-term average (7.1 °C). The deviation of the average monthly air temperature was + 1.4–2.2 °C in spring and + 1.9–2.8 °C in summer. The amount of precipitation in the 2016–2017 season was insufficient throughout the growing period (total precipitation: 688 mm). In April-May there was a decrease in rainfall by 11.7–4.2 mm. The subsequent period of intensive growth and crop formation was characterized by an even greater shortage in the summer months (June-August) - 13.6–34.5 mm. The second season was wet (887.5 mm), compared to the average long-term data (738 mm) (Fig. 1).

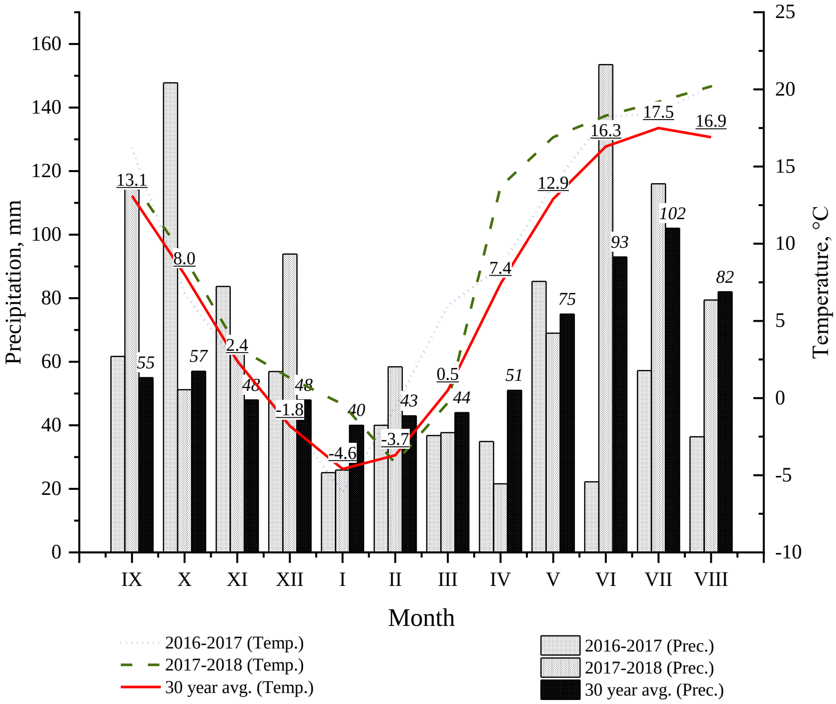

Figure 1. Agrometeorological parameters of the two growing seasons.

Statistical processing of the obtained research results was performed using OriginPro 2019b software (OriginLab Corporation, USA, 2019). Data were compared using the *Tukey test*. Differences between samples were considered statistically significant at $P < 0.05$. The data in the tables are presented as the arithmetic mean with standard deviation ($x \pm SD$).

RESULTS AND DISCUSSION

The intensity of CO_2 emission in the field of winter wheat was lowest in the control plots (var. 1) - 7.3–13.5 ppm min^{-1} and 8.7–13.0 ppm min^{-1} in the variant of the mineral fertilizing system (var. 15). Under the organo-mineral fertilizing system with liming with 1.0 n of $CaCO_3$ according to hydrolytic acidity (var. 7), it was 10.5–14.7 ppm min^{-1}. It slightly exceeded the same fertilizing system with lime application calculated by acid-base buffering capacity (var. 8).

In summer emission of CO_2 increased in all variants and amounted to 20.5 ppm min^{-1} in control and under mineral fertilization. In the variant of the organo-mineral fertilizing system with liming by 1.0 n of $CaCO_3$ according to hydrolytic acidity, it was 18.7 against 14.5 ppm min^{-1} of the same fertilizing system with $CaCO_3$ dose calculated by the acid-base buffering capacity. Calculation of lime dose by pH buffering capacity optimizes the CO_2 flow during a period of intensive growth and development of plants. Instead, the application of high doses of lime calculated by hydrolytic acidity contributes to the increase in mineralization processes and unproductive loss of soil carbon (Tsapko et al., 2018).

According to Fuentes et al. (2006), the fast CO_2 release from the soil after liming is a result of two parallel processes: a chemical process, as a consequence of the $CaCO_3$ hydrolysis reaction in the soil; a biological, caused by increased microbial activity due to improved soil conditions (higher pH, better availability of organic substrates etc.). The effect of lime on CO_2 release is proportional to the liming rate.

In a mineral fertilizing system with liming by 1.5 n of $CaCO_3$ according to hydrolytic acidity, the intensity of CO_2 release also exceeded the variant with the same fertilizing system on the background of lime application calculated by acid-base buffering capacity and was 17.2 and 13.5 ppm min^{-1} respectively (Fig. 2).

Thus, the dynamics of CO_2 emission in the field of winter wheat during plant growth and development confirms that the introduction of high doses of lime calculated by hydrolytic acidity is accompanied not only by significant material costs but also environmental problems, increasing the concentration of carbon dioxide in agroecosystems.

In our previous studies conducted in the VII-VIII crop rotations on Albic Stagnic Luvisol, it was found that emission of carbon dioxide in the field of corn for silage after application of lime and fertilizers as well as its aftereffect under spring barley is the highest in organo-mineral and mineral fertilizing systems on the background of liming with the 1.0–1.5 norm of $CaCO_3$ by hydrolytic acidity. It significantly outweighs the same fertilizing system with the background of liming by an optimal dose of $CaCO_3$ calculated by pH buffering capacity (Habriel et al., 2016).

It is noteworthy that under the mineral fertilizing system in the field of winter wheat, the intensity of CO_2 emission is quite high and close to absolute control. At a low level of crop formation (1.97–2.58 t ha^{-1}), this indicates additional losses of mobile organic matter compounds at high acidity of the soil solution (pH_{KCl} = 4.03 and 4.22 respectively). It was found in previous studies, that in these variants is a present accumulation of mobile 1 + 1 'a' fraction of fulvic acids, which are capable of rapid mineralization and migration in the soil profile (Snitynskyi et al., 2015). This dependence together with a decrease in pH_{KCl} indicates the negative consequences of this anthropogenic impact and leads to increased soil degradation.

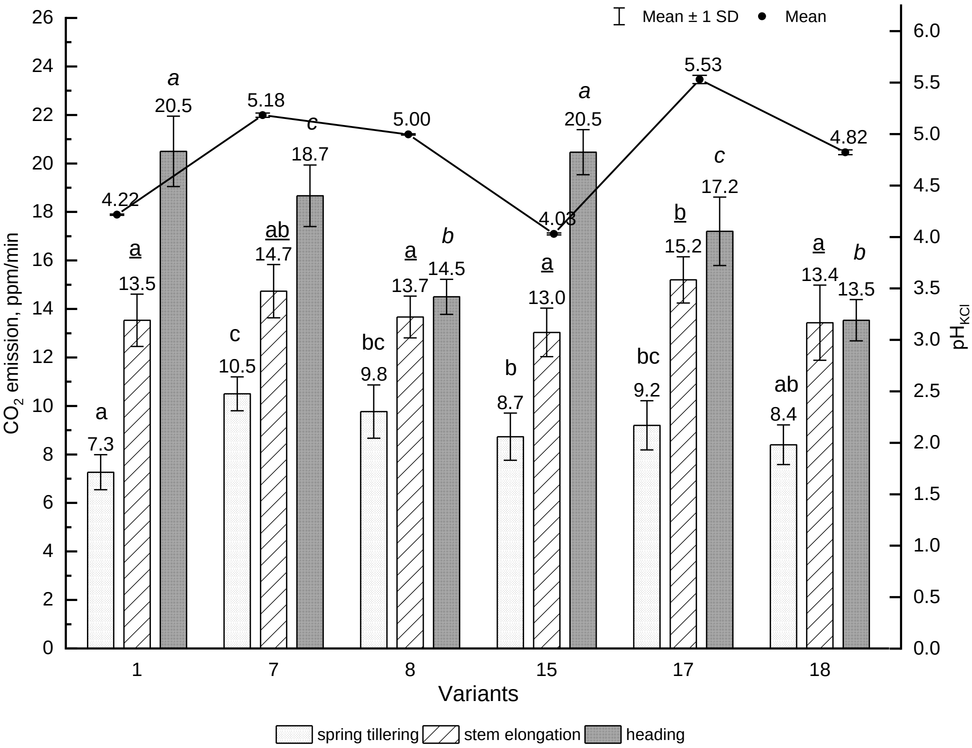

Figure 2. CO_2 emission under winter wheat during the period of intensive growth and development, the end of ninth crop rotation (*LSD_{05}* CO_2 - 0.52 ppm min^{-1}, n = 6). Mean values labelled with the same letter are not significantly different from each other according to the results of comparison using the *Tukey test* (P < 0.05); different lowercase letters indicate statistical significance between variants in the phase of spring tillering; underlined - in the phase of stem elongation; italic - in the heading phase.

Our studies have shown that during long-term ploughing (more than 50 years) of Albic Stagnic Luvisol on the variant without fertilizing (control), the redox potential in the profile varied from moderately oxidative 514 mV in arable and sub-arable soil horizons to weakly oxidative 494 mV in Ehg and 458 mV in Beg soil horizons. The pH_{KCl} in control underwent the following changes: 4.22; 4.18; 4.31; 4.13. Weak oxidative conditions (446 mV) at pH_{KCl} 4.22–4.47 were observed in the illuvial and BCg (440 mV) horizons. In parent CBg horizon, Eh was at the level of 437 mV. Long-term crop rotation, ploughing of organic residues (stubble, 2nd mow of meadow clover) in control without fertilizers leads to the development of weakly oxidative redox processes in the genetic horizons of the soil (Table 1).

Under organo-mineral fertilizing system on the background of liming with a full dose of $CaCO_3$ by hydrolytic acidity, there was a more contrasting change in Eh compared to the control. The elevated value of the Eh potential 628 mV in the AEg(arable) horizon indicates the development of intense oxidative processes in it. In AEg(sub-arable) and Ehg horizons, Clark's index is 29.3 and 27.1. Conditions in these layers are characterized as moderately oxidative. Down from Beg horizon (depth 51 cm), Eh varied sharply from weakly oxidative (420 mV) to weakly reductive processes in the underlying Bg and BCg genetic horizons (388–370 mV respectively). The lowest values of redox potential (363 mV) and weakly reductive redox regime for this fertilizing system was observed in strongly illuviated and strongly gleyed BCG horizon with Clark's index of 20.2 and pH_{KCl} of 4.05.

Prolonged application of only mineral fertilizers on Albic Stagnic Luvisol resulted in the redox potential decrease in all genetic horizons compared to the control without fertilizers (Table 1). Such changes are caused by unsatisfactory agrophysical soil properties, an increase in gley content, acidity, and mobile aluminium compounds, and a decrease in aeration and organic matter content (Tkachenko et al., 2017).

Table 1. Change of redox potential in the profile of Albic Stagnic Luvisol depending on different anthropogenic loads ($x \pm SD$, n = 6)

Genetic horizons	Horizon thickness (m)	pH_{KCl}	Eh (mV)	rH_2
Without fertilizers (control) (var. 1)				
AEg(arable)	0–0.18	4.22 ± 0.02^{a}	514 ± 7.1^{a}	25.6
AEg(sub-arable)	0.18–0.31	4.18 ± 0.01^{ac}	514 ± 7.2^{a}	25.5
Ehg	0.31–0.64	4.31 ± 0.01^{b}	494 ± 8.2^{a}	25.1
Beg	0.64–1.10	4.13 ± 0.01^{c}	458 ± 8.5^{b}	23.5
Bg	1.10–1.31	4.22 ± 0.03^{a}	446 ± 5.2^{b}	23.3
BCg	1.31–1.80	4.47 ± 0.02^{e}	440 ± 9.5^{b}	23.6
CBg	1.80–2.00	4.35 ± 0.03^{b}	437 ± 7.1^{b}	23.3
-	LSD_{05}	0.15	-	-
$N_{105}P_{101}K_{101}$ + 10 t of manure per ha + $CaCO_3$ (1.0 by hydrolytic acidity) (var. 12)				
AEg(arable)	0–0.20	5.15 ± 0.01^{a}	628 ± 11.5^{a}	31.2
AEg(sub-arable)	0.20–33	5.10 ± 0.01^{b}	575 ± 11.2^{b}	29.3
Ehg	0.33–0.51	4.24 ± 0.02^{c}	560 ± 6.7^{b}	27.1
Beg	0.51–0.77	3.88 ± 0.01^{d}	420 ± 6.0^{c}	21.7
Bg	0.77–1.38	3.85 ± 0.01^{d}	388 ± 6.0^{d}	20.6
BCg	1.38–1.87	3.97 ± 0.01^{e}	370 ± 6.8^{de}	20.2
BCG	1.87–2.10	4.05 ± 0.02^{f}	363 ± 5.7^{e}	20.2
-	LSD_{05}	0.74	-	-
$N_{65}P_{68}K_{68}$ (var. 15)				
AEg(arable)	0–0.22	4.03 ± 0.01^{ad}	426 ± 10.3^{a}	22.3
AEg(sub-arable)	0.22–0.35	3.98 ± 0.01^{bd}	416 ± 12.0^{ba}	21.8
Ehg	0.35–0.61	4.17 ± 0.01^{c}	398 ± 8.5^{b}	21.6
Beg	0.61–0.87	4.00 ± 0.01^{d}	368 ± 8.7^{c}	20.3
Bg	0.87–1.50	4.07 ± 0.01^{a}	323 ± 6.4^{d}	18.9
BCg	1.50–1.80	4.04 ± 0.01^{a}	318 ± 9.6^{d}	18.7
CBG	1.80–2.00	4.11 ± 0.02^{e}	311 ± 5.9^{d}	18.6
-	LSD_{05}	0.09	-	-

Note: values that have at least one identical letter within a table row do not differ in the *Tukey test* (P < 0.05).

Decreased redox potential leads to excessive accumulation of Fe^{2+}, Mn^{2+} and Al^{3+} compounds, toxic to plants (Kyrylchuk & Bonishko, 2011). This contributes to even greater acidification of soils and adversely affect plant nutrition, which ultimately dramatically reduces crop yields and leads to soil degradation.

As a result, the inclusion of Albic Stagnic Luvisol in the system of agriculture while using only mineral fertilizers is accompanied by changes in the redox potential in the direction of reduction - i.e., strengthening of reductive processes.

At the same time, a decrease of Eh value in the lower soil horizons in the mineral fertilizing system and control variants also indicates an increase in reductive processes due to worsening of aeration consequently to soil waterlogging, which is due to disruption of soil air exchange with atmospheric air and significantly reduced oxygen diffusion rate.

Redox fluctuations influencing the microbial cenosis of the soil. In particular, fungi grow better than bacteria under moderate reduction conditions at Eh > + 250 mV, while bacteria grow better at Eh < 0 (Seo & DeLaune, 2010). Similarly, each species of microorganism is adapted to a certain pH range (Lauber et al., 2009).

The reason for the low biological activity of control and in the case of long-term use of the only mineral fertilizing system is a small number of crop residues used by microflora as nutrient and energy material at high acidity of the soil solution (pH_{KCl} 4.20–4.05, hydrolytic acidity 4.68–5.03 cmol kg^{-1} of soil).

Studies have shown that the mineral fertilizing system with optimal norms of lime calculated by acid-base buffering capacity together with a decrease in pH_{KCl} to 4.56 and an increase in hydrolytic acidity to 3.77 cmol kg^{-1} of soil caused a decrease in total biological and protease activity to 22.70 and 4.15 % respectively. Under this fertilizing system, but with $CaCO_3$ application according to hydrolytic acidity (pH_{KCl} 5.65, hydrolytic acidity 1.80 cmol kg^{-1} of soil), total biological and protease activities were higher and amounted to 29.47 and 4.52 % respectively. Therefore, there is a direct relationship between the value of acidity (pH_{KCl}) and biological activity of the soil.

The number of microorganisms in soil depends on and liming. The largest number of aerobic bacteria in one gram of soil (microbial count) was found in the variant with a joint application of mineral, organic fertilizers and liming - 3.4 10^{10} CFU g^{-1}. The smallest amount 2.8 10^{7} CFU g^{-1} was in the control and the mineral fertilizing system. The application of manure and lime had a particularly favourable effect on the number of saprophytic bacteria, increasing their number by 2–4 times compared to the control and the variant with mineral fertilizing. This is primarily due to the much larger inflow of organic residues into the soil and the acidity neutralization of the soil solution.

Unsatisfactory physicochemical properties of the soil in mineral fertilizing and control variants are due to the critically low pH_{KCl} value (4.05–4.22) for the growth and development of most crops, high content of mobile aluminium compounds (11.8–60.0 mg kg^{-1}), calcium deficiency (20–18 mg kg^{-1}), humate-fulvate type of humus ($C_{HA} : C_{FA} = 0.64$). Under such unfavourable soil conditions, the growth and development of the plants' root system, its functional properties (both absorbable and excretory) are slowed down.

The largest number of moulds was observed in the control without fertilizers and only mineral fertilizers variants (17–18 thousand CFU g^{-1} of soil). In the variants of organo-mineral and mineral fertilizing with liming, the number of micromycetes decreased to 10–9 thousand CFU g^{-1} of soil.

Studies conducted in the long-term stationary experiment of the Institute of ACR showed that the content of the Escherichia coli bacteria group, which belong to potentially pathogenic bacteria and have high environmental plasticity, is significantly lower than the content of other microorganisms. It changes slightly in the experimental variants and their number to some extent depends on humidity and temperature (Snitynskyi et al., 2014).

Systematic fertilization and periodic liming improve the physicochemical, agrochemical and biological properties, primarily due to the reduction of soil acidity. So it is possible to obtain rather high and stable yields of crops in the conditions of Albic Stagnic Luvisol.

The highest grain yield of winter wheat (5.53 ± 0.58 t ha^{-1}) was provided by the organo-mineral fertilizing system with periodic liming by one norm of lime. The increase is 3.56 t ha^{-1} compared to the control without fertilizers, where the value of winter wheat yield was 1.97 ± 0.29 t ha^{-1}. The use of the same fertilizing system but with an application of an optimal lime dose calculated according to acid-base buffering capacity increased the yield of winter wheat to 5.05 ± 0.32 t ha^{-1} (Fig. 3).

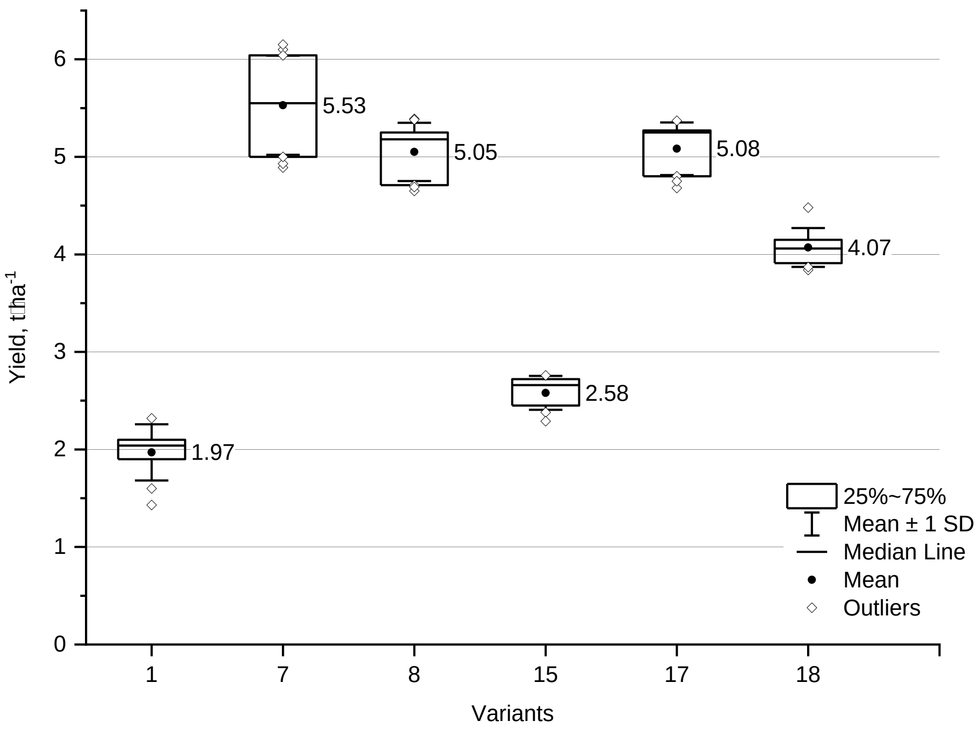

Figure 3. Influence of different fertilizing systems and periodic liming on the yield of winter wheat, t ha^{-1} (*n* = 9).

Intensive mineral fertilizing with an application of only mineral fertilizers in crop rotation for more than 50 years provided a winter wheat yield of 2.58 ± 0.12 t ha^{-1}, which is only 0.61 higher than the control variant. A sufficiently high winter wheat productivity (5.09 ± 0.31 t ha^{-1}) was ensured by the joint application of 1.5 norms of mineral fertilizers and 1.5 norms of $CaCO_3$ according to hydrolytic acidity. Liming with a dose of $CaCO_3$ calculated by acid-base buffering capacity formed a slightly lower yield of 4.08 ± 0.20 t ha^{-1}.

The traditional acidic soils cultivation system of applying high doses of lime, calculated according to hydrolytic acidity does not provide progressive development of soil formation processes on an environmentally friendly basis due to significant leaching of calcium in groundwater, excessive mineralization and emission of carbon dioxide. In short-term crop rotation, it is expedient to apply lime fertilizers at a dose calculated by pH buffering capacity with repeated liming before each of the following rotations (shorter than 5-year interval) (Loide, 2010.). It will provide a gradual shift of acid-base balance and environmentally safe use of acidic soils.

CONCLUSIONS

It is advisable to use carbon dioxide emission, redox potential and biotic activity along with agronomic characteristics as informative diagnostic indices of Albic Stagnic Luvisol to substantiate the optimal doses of fertilizers and lime, ensure balanced natural cycles of substances and high fertility level. They allow quantifying different levels of anthropogenic impact on the transformation of the agroecosystems.

An organo-mineral fertilizing system with liming by $CaCO_3$ dose based on pH buffering capacity optimizes carbon dioxide emission to the greatest extent by creating oxidative and moderately oxidative conditions, increasing the number of aerobic bacteria and overall biological activity. Mineral fertilizing system and the inclusion of Albic Stagnic Luvisol in agriculture without fertilizers provide a low level of crop productivity, which is accompanied by additional CO_2 losses due to mineralization of mobile humus compounds. Together with a decrease in pH_{KCl}, it leads to a strengthening of reductive processes and soil degradation. Such conditions ensure a decrease in total biological and protease activity and an increase in the number of fungal microflorae.

Thus, in short crop rotations, it is advisable to apply lime fertilizers at a dose calculated by pH buffering capacity with repeated liming before each rotation. This will ensure a gradual shift in acid-base balance and environmentally safe use of acidic soils while obtaining high productivity.

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