Journal of Elementology ISSN 1644-2296

Poliovyy V., Snitynskyy V., Hnativ P., Szulc W., Lahush N., Ivaniuk V., Furmanets M., Kulyk S., Balkovskyy V., Poliukhovych M., Rutkowska B. 2021. *Agro-ecological efficiency of a crop fertilization system with the use of phytomass residues in the western forest steppe of Ukraine.* J. Elem., 26(2): 433-445. DOI: 10.5601/jelem.2021.26.1.2120

RECEIVED: 25 February 2021
ACCEPTED: 27 May 2021

ORIGINAL PAPER

AGRO-ECOLOGICAL EFFICIENCY OF A CROP FERTILIZATION SYSTEM WITH THE USE OF PHYTOMASS RESIDUES IN THE WESTERN FOREST STEPPE OF UKRAINE*

Volodymyr Poliovyy[1], Volodymyr Snitynskyy[2], Petro Hnativ[2], Wieslaw Szulc[3], Natalia Lahush[2], Viktor Ivaniuk[2], Myroslava Furmanets[1], Svitlana Kulyk,[1] Volodymyr Balkovskyy[2], Mariia Poliukhovych[2], Beata Rutkowska[3]

[1] Institute of Agriculture of the Western Polissia of the NAAS Rivne, Ukraine
[2] Lviv National Agrarian University, Lviv, Ukraine
[3] Agricultural Institute Warsaw University of Life Sciences, Warszawa, Poland

Abstract

Fertilization of field crops and maintenance of soil fertility by mineral fertilization only do not secure a positive balance and ratio of nutrients and humus in arable farming. In 2009-2018, a long-term field experiment of four-crop rotation system (winter oilseed rape – winter wheat – grain maize – spring barley) determined the efficiency of using phytomass residues (including the application of N_{10} ammonium nitrate per 1 ton of the previous crop straw). The experiment was conducted on dark-grey podzolic soil (*Luvic Greyic Phaeozem* – WRB (2015) with a 1.9% share of humus, 99 mg kg^{-1} of alkaline hydrolyzable nitrogen (by Cornfield), 105 and 71 mg kg^{-1} of mobile phosphorus and exchangeable potassium (by the Kirsanov method), respectively. The work demonstrates agro-chemical and physical-chemical transformations in soil and determines changes in the yield of crops grown in a crop rotation system. The use of a non-marketable component of the yield of winter wheat, grain maize, spring barley and winter oilseed rape (phytomass residues) for fertilization secured replenishment of the soil with 46.0 kg ha^{1} of nitrogen, 7.9 kg ha^{-1} of phosphorus and 75.5 kg ha^{-1} of potassium per 1 ha of crop rotation that

Wiesław Szulc, PhD DSc, Prof. UPP, Independent Department of Agricultural Chemistry, Agricultural Institute, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787 Warsaw, Poland, e-mail: wieslaw_szulc@sggw.edu.pl; ORCID https://orcid.org/0000-0001-8505-0514

* Study financially supported by Institute of Agriculture of Western Polissia of NAAS, manager Volodymyr Polovyy, 5 Rivne Street, Shubkiv, Rivne district, Rivne region, 35325, Ukraine, +380673608317, e-mail: rivne_apv@ukr.net

accounted for 15.9; 15.9 and 37.0% of their total loss, respectively. With the combination of mineral fertilizers and by-products, a positive balance of nitrogen, phosphorus and potassium was achieved with amounts of 24.4 15.1 and 42.7 kg ha^{-1} of the nutrients, respectively. Supplementing the mineral system of fertilization with phytomass residues as a fertilizer secured an increase of the amount of alkaline hydrolysable nitrogen by 5.1%, mobile phosphorus – by 4.6, and exchangeable potassium – by 103.5%, as compared to the pure mineral system of fertilization. However, it is necessary to control physical and chemical properties of the soil, and to maintain the reaction of soil solution within the optimal limits.

Keywords: fertilizers, soil, humus, nitrogen, phosphorus, potassium, balance

INTRODUCTION

The livestock of cattle and pigs in Ukraine has decreased by 2.9- and 1.3-fold, respectively, in the recent 20 years. This has led to a reduction of amounts of manure applied to soil from 2.5 to 1.3 Mg ha^{-1} of arable land. Thus, the current problem in arable farming is to maintain the organic matter in soil, mainly by fertilizing it with phytomass residues. Such an approach (Degodyuk et al. 2013, Truskavetsky, Tsapko 2016, Hnativ et al. 2019) secures a positive balance of humus in soil in Ukraine.

Organic inputs can help maintain soil fertility by improving chemical and biological soil properties. The effects of 40-year-long organic, mineral and mixed fertilization on soil organic properties were evaluated in a continuous maize cropping system. Total organic carbon (TOC) and humic carbon (HC) in soil were analyzed (Nardi et al. 2004). Farmyard manure fertilization sustained TOC in the top layers while mineral treatments alone or mixed with organic ones had a minor influence on the organic matter evolution: over 40 years, the average TOC depletion was 23% with liquid manure and mixed fertilization, 43% with mineral fertilizers alone and 51% in the control.

Earlier, we reported that according to the research conducted in 1976-1983 on dark-grey podzolic soil, the economically optimal balance of nutrients in a typical crop rotation system of cereals and other crops over ten years was ensured by the application of 12 Mg ha^{-1} of manure and N90P70K70 per 1 ha in crop rotation (Yakubovskaya et al. 1988). The level of nutrient replenishment in soil was 91.5% for nitrogen, 206.4% for phosphorus and 79.6% for potassium under the organic and mineral fertilization system.

In both purely theoretical and applied scientific studies, the issue of a rational use of non-marketable phytomass of field crops in arable farming is given much attention (Liu et al. 2010, Karami et al. 2012, Degodyuk et al. 2013, Akhtara et al. 2019). The Ukrainian agrarian science and practice considers by-products of crop production primarily as a source of soil replenishment with organic matter. Moreover, such biomass contains many biogenic elements, which are available for plant nutrition in the process of mineralization and which actively influence their growth and development

(Bakht et al. 2009, Kraska 2012, Truskavetsky, Tsapko 2016, Zhang et al. 2016). The nutrients which come into soil with phytomass residues replenish the resource of mineral salts in it.

The aim of the current research is to determine the impact of using phytomass residues in a fertilization system on the balance of nutrients in dark-grey podzolic soil, as well as on the indices of its fertility and yield capacity of crops in a crop rotation system.

MATERIAL AND METHODS

The research was conducted in 2009-2018 as a long-term field experiment of a four-crop short-rotation system, i.e. winter oilseed rape – winter wheat – grain maize – spring barley. The experiment was carried out at the Institute of Agriculture of Western Polissia of the NAAS.

The experiment included the following variants of using phytomass residues: 1) removal of resides from the field, i.e. the variant without straw as a fertilizer; 2) fertilization – straw as a fertilizer + N_{10} ammonia nitrate per 1 ton of previous crop straw.

After harvesting each preceding crop, the introduction of compensatory nitrogen N10 was carried out for rapid decomposition of the plant residues. Tillage for crops included disking to the depth of 10-12 cm, plowing to the depth of 23-25 cm for grain maize and 20-22 cm for the other crops. Mineral fertilizers were applied for the crops in the crop rotation system in the form of ammonia nitrate (NH_4NO_3 – 34%N), potassium salt (KCl – 40%) and ammonium phosphate ($(NH_4)_2HPO_4$ – 18% N). Phosphorus-potassium fertilizers were applied during the principal soil treatment, whereas nitrogenous ones – during the pre-cropping treatment.

Crop fertilization system:

Winter wheat – P90K120 for plowing, N30 for cultivation, fertilization N60 in early spring at the stage of resumed plant growth and N60 at the stage of stem elongation before ear emergence;

Maize for grain – P90K120 in autumn for plowing, N120 in spring for cultivation;

Spring barley – P90K90 in autumn for plowing, N90 in spring for cultivation;

Winter rape – P90K150 for plowing, N30 for cultivation, fertilization N80 in early spring in the resumed plant growth and N40 in the stalk phase, the beginning of budding.

The following plants were sown: the variety of winter wheat Astarte, spring barley Avatar, hybrid maize DKS 3972, hybrid of winter oilseed rape DK Exquisite.

The following herbicides were used to control weeds:

Winter wheat – post-emergence herbicide Rimax Plus – 30 g ha^{-1};

Maize for grain – pre-emergence soil herbicide Proxanil – 2-3 l ha^{-1}; post-emergence herbicide Milagro 240 – 0.16-0.2 l ha^{-1} + surfactant;

Spring barley – post-emergence herbicide Rimax Plus – 30 g ha^{-1};

Winter oilseed rape – post-emergence herbicide Halo Maxi – 0.8-1.2 l ha^{-1}.

Disease protection:

Winter wheat – Birex – 0.6 l ha^{-1}, Colossal Pro – 0.4 l ha^{-1};

Maize for grain – Retengo – 0.5 l ha^{-1};

Spring barley – Birex – 0.6 l ha^{-1}, Colossal Pro – 0.4 l ha^{-1};

Winter oilseed rape – Colossal Pro – 0.4 l ha^{-1}, Rydomil Gold – 2.5 kg ha^{-1}, Pictor – 0.5 l ha^{-1}.

Pest protection:

Winter oilseed rape – Volley – 0.5–0.6 l ha^{-1}, Mospilan – 0.10-0.12 kg ha^{-1}, Borei – 0.6 l ha^{-1};

Winter wheat – Volley – 0.75-1.0 l ha^{-1}, Borei – 0.1 l ha^{-1};

Spring barley – Borei – 0.1 l ha^{-1}.

The experiment was conducted on dark-grey podzolic soil (*Luvic Greyic Phaeozem* – WRB (2015) with 1.9% of the humus share, 99 mg kg^{-1}of alkaline hydrolyzable nitrogen (by Cornfield), 105 and 71 mg kg^{-1} of mobile phosphorus and exchangeable potassium (by the Kirsanov method), respectively.

The laboratory analyses were conducted according to the standard methodology (State Standard…, 2005, 2015, 2015, Hnativ et al. 2019). Statistical analyses were performed with the Statgraphics 5.1 software (The Plains, USA). The results were subjected to one-way analysis of variance (ANOVA) with a *p* value of 0.05, Student's *t*-test and Pearson's linear correlation analysis.

RESULTS AND DISCUSSION

The removal of soil nutrients depends on many factors. However, the principal ones include the kind of field crop and its yield capacity. The performed calculations demonstrate that the loss of nitrogen in the four-year crop rotation system varied within 175.2-303.2, phosphorus – within 57.1-103.7, potassium – 93.9-271.8 kg ha^{-1}, depending on the crop (Figure 1). On average for a whole crop rotation, consumption of the mentioned elements reached 223.2; 74.7 and 169.3 kg ha^{-1} respectively in the variant consisting of the removal of phytomass residues, and 244.4, 74.5 and 170.1 kg ha^{-1} in the variant where phytomass residues were used for fertilization.

Development of an agro-ecological-economically balanced system of fertilization in a crop rotation, particularly an adequate supply of nutrients, requi-

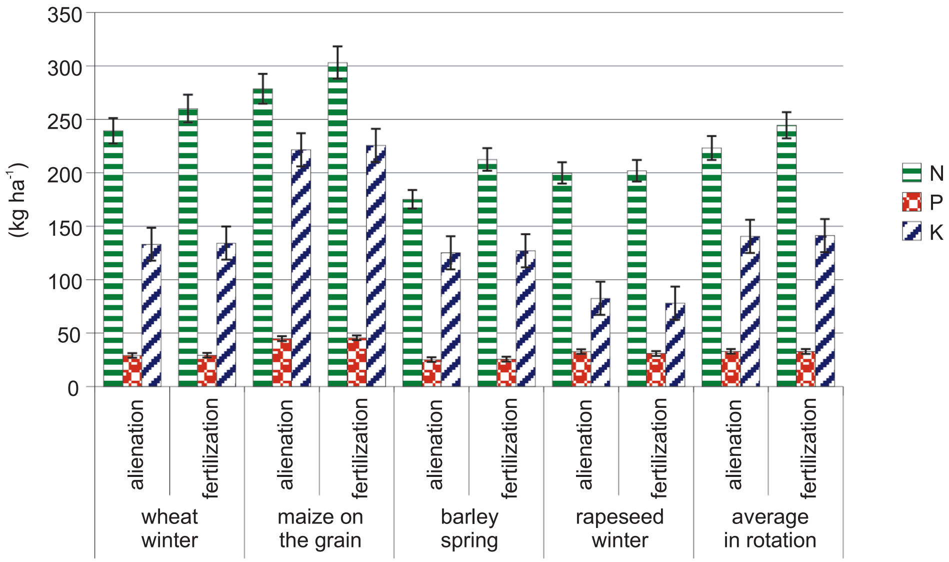

Fig. 1. The removal of soil nutrients depending on the use of phytomass residues, kg ha^{-1} (average for 2009–2018) (p<0.05 error bars – standard error SE)

res calculating the volume of nutrients removed from the soil by field crops (Liu et al. 2010, Sienkiewicz et al. 2011, McGrath et al. 2014).

Comparative evaluation of the N, P and K removal indices demonstrated that they changed within a wide range depending on the crops of the rotation system. The impact of crop residues on the volume of yield was insignificant as proven by yields in the variant with their use for fertilization being close to ones in the variant with the removal of crop residues from the field.

The highest indices of the loss of soil nutrients in the fertilization systems with and without by-products were 303.2 and 278.6 for nitrogen, 45.6 and 44.8 for phosphorus, and 225.6 and 221.5 kg ha^{-1} potassium, respectively, under grain maize. Similar results were also determined by other scientists (Akhtar et al. 2018). According to the volume of NPK removal, the other crops of the tested crop rotation system were arranged in the following order: winter wheat, spring barley, winter oilseed rape.

The volume of nutrients supplied into soil from fertilization with phytomass residues depends on a crop (Figure 2). Grain maize supplies the greatest amount of nitrogen when its remains are used as fertilizer. The same is true about nitrogen as well as phosphorus and potassium. The least volume of nutrients is supplied by phytomass residues of spring barley and winter oilseed rape.

Thirty-five years ago, the volume of applied mineral fertilizers in the arable farming of Ukraine was twice as high and much more manure was supplied under crops. This secured a favorable balance of nutrients for 10-20 years of crop rotations.

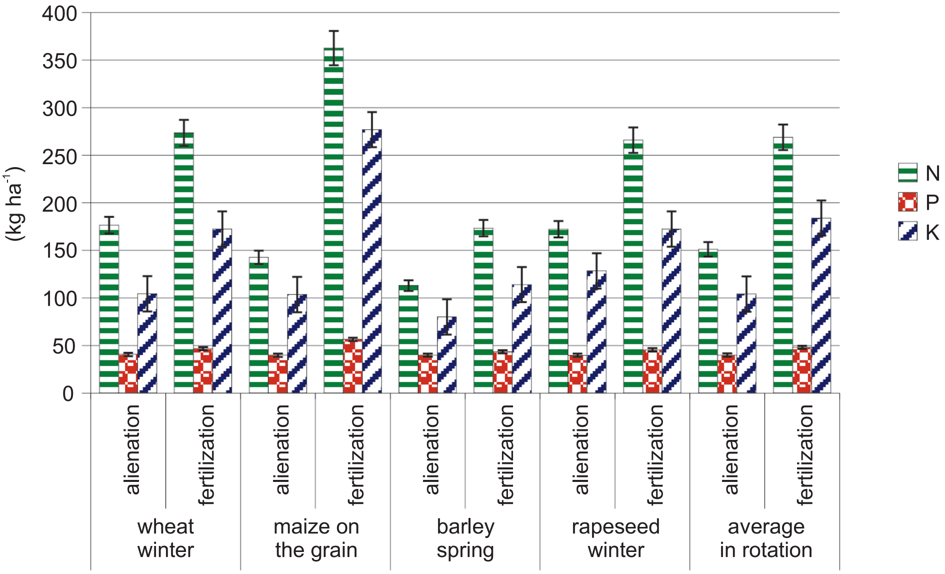

Fig. 2. Supply of nutrients to soil depending on the use of phytomass residues, kg ha^{-1} (average for 2009–2018) (p<0.05 error bars – standard error SE)

According to the research conducted in 1976-1983 on dark-grey podzolic soil, the economically optimal balance of nutrients in a typical crop rotation of cereals and tilled crops of a ten-year system was supplied by the application of 12 Mg ha^{-1} of manure and $N_{90}P_{70}K_{70}$ per 1 ha under crop rotation (Yakubovskaya et al. 1988). The level of nutrient replenishment in soil was 91.5% for nitrogen, 206.4% for phosphorus and 79.6% for potassium in an organic-mineral system of fertilization.

Currently, non-marketable phytomass residues are mainly used in Ukraine for the fertilization purpose, which considerably improves the balance of nitrogen and nutrients in soil. Results of the authors' research confirmed that winter wheat straw secured replenishment of soil with 31.0 kg ha^{-1} of N, 6.2 kg ha^{-1} of P and 51.5 kg ha^{-1} of K, or 11.5; 13.2 and 29.8% of the total removal by the yield, respectively (Table 1).

When stem and leaf residues of maize are used for fertilization, the soil is supplied with 96.0, 16.7 and 173.5 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively, which covers 26.5, 29.7 and 62.6% of the nutrient removal.

The straw of barley and oilseed rape replenished the soil with 11.5 and 13.9% of nitrogen, 8.1 and 12.6% of phosphorus relative to the removed amounts, and 29.9 and 25.5% of potassium, respectively These data confirm the importance of crop residues as a source to replenish the pool of nutrients, primarily potassium, in soil.

The balance of elements in soil is one of the main criteria in an agro-ecological evaluation of the efficiency of a fertilization system for some field

Table 1

Balance of nutrients in soil depending on the use of crop residues (average for 2009-2018)

Crop in the rotation system	Use of phytomass residues	Replenishment of soil by phytomass residues (kg/%) as compared to their removal			Balance +, –		
		N	P	K	N	P	K
Winter wheat	alienation	–	–	–	–62.90	+26.10	–34.80
	fertilization	31.00	6.20	51.50	+13.40	+39.50	+46.10
		11.50	13.20	29.80			
Grain maize	alienation	–	–	–	–136.1	–11.70	–142.3
	fertilization	96.00	16.70	173.5	+59.40	+24.40	+61.80
		26.50	29.70	62.60			
Spring barley	alienation	–	–	–	–62.30	+33.30	–54.40
	fertilization	20.00	3.500	34.00	–39.20	+40.40	–15.70
		11.50	8.100	29.90			
Winter rape	alienation	–	–	–	–27.60	+15.60	+55.30
	fertilization	37.00	5.700	44.00	+64.00	+32.90	+113.7
		13.90	12.60	25.50			
Average in rotation	alienation	–	–	–	–72.20	+15.90	–44.00
	fertilization	46.00	7.900	75.50	+24.40	+34.30	+51.50
		15.90	15.90	37.00			

crops, crop rotations and arable farming in total (Hnativ et al. 2019). Comparison of the balance of N, P and K in soil under the crops in a crop rotation system between the two variants: with and without the removal of plant residues after harvest demonstrates that the latter secures significant improvement of the indices of nutrients. When straw is removed before growing winter wheat, a negative balance of nitrogen and potassium appears. However, when straw residues are plowed into soil, these nutrients reach a positive balance.

A particularly great impact on the NPK balance is by achieved by the stem and leaf residues of maize. Withdrawal of such residues from a field leads to a sharp negative balance of nitrogen (–136.1 kg ha^{-1}) and potassium (–118.1 kg ha^{-1}), whereas if it is used for fertilization, the level of nitrogen nears the balanced value while the balance of phosphorus and potassium is positive. Among the crops of the crop rotation system tested, spring barley produces the least volume of residues and consequently its impact on the NPK balance is weaker.

Plowing the straw of winter oilseed rape into the soil contributed to the formation of a positive balance of nitrogen (+64.0 kg ha^{-1}), phosphorus (+14.5 kg ha^{-1}) and potassium (+94.4 kg ha^{-1}). The data presented in this article do not confirm the popular idea that oilseed rape is a crop which exhausts soil resources. Cultivation of agricultural crops does not cause soil degradation as long as the requirements of scientifically developed fertilization systems of and arable farming principles are followed.

The balance calculations facilitate optimization of the system of fertilization of agricultural crops in order to achieve the planned yield, in addition to which they can influence decisions to take measures which affect the content of some nutrients in soil. Most soils contain large amounts of phosphorus and potassium, and plants can use those elements for many years, whereas the soil reserves of nitrogen should be sustained through the application of nitrogen fertilizers in an amount which is larger than the consumed one. This can be explained by complicated transformations nitrogen in the "soil-plant-fertilizers-water" system (Coppens et al. 2006, Liu et al. 2010, Malhi 2011, McGrath et al. 2014).

The experiments with nitrogen fertilizers marked by a stable isotope of nitrogen demonstrate that mineral forms of nitrogen are transformed many times, i.e. fixing with organic matter, ammonification, nitrification, denitrification and others. According to the available research results, there is no relationship between the nitrogen balance indices and content of alkaline hydrolyzable nitrogen in soil. The variant composed of the application of recommended doses of mineral fertilizers showed that the content of alkaline hydrolyzable compounds of nitrogen was reduced to 93 mg kg^{-1} after the first rotation, comparing to the initial 99 mg kg^{-1} of soil. However, after the second crop rotation, it increased to 111 mg kg^{-1} of soil (Table 2).

In the variant with the application of the recommended doses of mineral fertilizers in combination with crop residues and compensation nitrogen, although the nitrogen balance shifted from negative to positive, the volume of its available forms was reduced from 99 to 82 mg kg^{-1} of soil during the first crop rotation. However, during the second crop rotation, it increased to 104 mg kg^{-1} of soil. Thus, the nitrogen which entered the soil with crop residues and ammonia nitrate for reduction of the C : N ratio significantly improved its balance in the soil (Malhi et al. 2011), as well as causing higher acidification and reduction of the share of alkaline hydrolyzable N compounds, as compared to the application of the recommended doses of mineral fertilizers alone.

The phytomass residues serve as an important source to replenish the soil with phosphorus. Its reutilization replenished the soil with an additional 14.9 kg ha^{-1} of P on average for two crop rotations, which corresponded to 15.9% of its removal. However, despite the positive balance of mobile phosphorus in soil, both under the application of recommended doses of mineral fertilizers only and in combination with phytomass residues, it did not secure a significant rise of its content in the soil. Based on mineral fertilization, it was reduced from the initial 105 mg kg^{-1} of soil to 90 and 98 mg kg^{-1} after the first and the second rotation, respectively. In the variant of mineral

Table 2

Change of the soil fertility indices under the effect of mineral fertilizers and crop residues

Way of phytomass residues use	Period of research	Fertilization (average per 1 ha of crop rotation)					Soil index			
		fertilizers, kg of active materials			phytomass residues (Mg ha^{-1})	compensation nitrogen (kg ha^{-1})	$N_{light.}$ (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	pH_{KCl}
		N	P	K						
Alienation	before the experiment start (2009)	128.0	90.00	120.0	–	–	99	105	71	5.3
	at the end of the 1st rotation (2014)						93	90	78	5.3
	at the end of the 2nd rotation (2018)						111	98	121	4.8
Fertilization	before the experiment start (2009)	128.0	90.00	120.0	7.180	71.80	99	105	71	5.3
	at the end of the 1st rotation (2014)						82	98	127	4.9
	at the end of the 2nd rotation (2018)						104	110	144	4.5

fertilizers combined with non-marketable phytomass in the first rotation, the share of P fell to 98 mg kg^{-1} of soil, and increased to 110 mg kg^{-1}only during the second rotation of crops.

The above data confirm the conclusions drawn by some other authors (DEVAU et al. 2009, JOKUBAUSKAITE et al. 2015, CEROZI, FITZSIMMONS 2016) concerning the deterioration of phosphorus mobility under increased acidity of soil.

Under conditions of the increased acidity of soil environment, the share of mobile compounds of potassium in soil increased regardless of the negative indices of balance. Application of NPK per 1 ha of crop rotation caused its increase up to 78 i 121 mg kg^{-1} of soil in the first and the second rotation respectively, comparing to 71 mg kg^{-1} at the beginning of the experiment. The use of straw as well as leaf and stem residues of crops for fertilization additionally replenished the soil with 75.5 kg ha^{-1} of potassium. Thus, its content increased up to 144 mg kg^{-1} of soil at the end of the second rotation, being 45% higher than the initial amount. An increase in the share of mobile potassium in soil under its balance deficit can be caused by more active transformation of its non-exchangeable forms into exchangeable ones under conditions of progressive reduction of base saturation of the soil absorption complex (ŠKARPA, HLUŠEK 2012).

Soil acidification is one of the main soil degradation processes, hindering the growth of crop yield. The tendency is intensified by an increase of applied mineral fertilizers. According to the research (Mazur 2008) results, application of mineral fertilizers in the doses of $N_{45}P_{45}K_{45}$, $N_{90}P_{90}K_{90}$ and $N_{135}P_{135}K_{135}$ in a field crop rotation during 45 years caused reduction of pH_{KCl} of the soil solution to 5.0, 4.8 and 4.6, respectively, from 6.2 at the onset of the experiment.

According to the results of this research, after the first rotation of crops, there was a rapid growth of exchangeable acidity, particularly after the application of compensation nitrogen. The application of NPK on average per 1 ha of crop rotation with no use of phytomass residues for fertilization in the first rotation did not cause a shift in pH_{KCl}, comparing to the initial one before the experiment. However, the inclusion of 7.18 Mg of phytomass residues and 71.8 kg of compensation nitrogen in the system of fertilization per 1 ha of crop rotation caused reduction of pH_{KCl} of soil solution to 4.9.

During the second rotation, an increase of acidity of the soil environment from 5.3 to 4.8 pH_{KCl} was observed also under the application of the recommended NPK doses alone. Their application together with phytomass residues and an additional dose of nitrogen caused a change of the reaction of the soil solution towards an acid one, namely from 4.9 to 4.5 pH_{KCl}.

Thus, application of elevated doses of mineral fertilizers, particularly nitrogen ones, during the eight years of the experiment set up on light loamy soils poor in humus caused its rapid acidification with a transition from the group of light acid soils to heavy acid ones.

The analysis of the impact of a fertilization system on yield capacity of crops in the crop rotation system demonstrates that the application of $N_{150}P_{90}K_{150}$ for winter wheat, $N_{120}P_{90}K_{120}$ for grain maize, $N_{90}P_{90}K_{90}$ for spring barley, and $N_{150}P_{90}K_{150}$ for winter oilseed rape secured their average yield of 6.56, 10.15, 5.68, 3.09 $t\ ha^{-1}$, respectively (Table 3).

Supplementation of the examined doses of mineral fertilizers with 7.18 t of phytomass residues and 71.8 kg of compensation nitrogen per 1 ha of crop

Table 3

Impact of crop residues on the yield of crops in the crop rotation system ($Mg\ ha^{-1}$), average for 2009-2018

Crop of the rotation system	Use of phytomass residues		Growth		Least significant difference *0*>0.05 ($Mg\ ha^{-1}$)
	alienation	fertilization	($t\ ha^{-1}$)	(%)	
Winter wheat	6.560	6.610	0.050	0.760	0.270
Grain maize	10.15	10.34	0.190	1.870	0.400
Spring barley	5.680	5.770	0.090	1.580	0.280
Winter rape	3.210	3.030	–0.180	–	0.250

rotation area demonstrated a slight, positive tendency of the impact on yield of winter wheat, grain maize and spring barley, but a negative one on the yield of winter oilseed rape (from 3.21 to 3.03 t ha^{-1} or by 5.6%). It can be partially explained by the considerable acidification of the soil. However, there was no statistically significant difference between those yields.

CONCLUSIONS

The use of non-marketable components of the yield of winter wheat, grain maize, spring barley and winter oilseed rape secured replenishment of soil with 46.0 kg ha^{-1} of nitrogen, 7.9 kg ha^{-1} of phosphorus, and 75.5 kg ha^{-1} of potassium, which corresponded to 15.9, 15.9 and 37.0% of the total removal respectively per 1 ha of a four crop rotation.

Along with the application of the recommended doses of mineral fertilizers only, the negative balance of nitrogen and potassium equaled: –72.2 and –36.5 kg ha^{-1}, respectively, and while that os phosphorus was +14.5 kg ha^{-1} on average for two rotations of crops. A combined application of mineral fertilizers and crop phytomass residues established a positive balance of nitrogen, phosphorus and potassium, which reached 24.4, 15.1 and 42.7 kg ha^{-1} of the balance, respectively.

In this fertilization variant, the share of alkaline hydrolyzable nitrogen increased from 99 to 111 mg kg^{-1} of soil, and potassium increased from 71 to 121 mg kg^{-1}, whereas phosphorus decreased from 105 to 98 mg kg^{-1} at the end of the second rotation. Supplementing mineral fertilization with crop phytomass residues secured an increase of the volume of easily hydrolyzed forms of nitrogen by 5.1%, mobile compounds of phosphorus – by 4.6%, and potassium – by 103.5%, comparing to the initial indices.

Retention of the non-marketable component of crop yield, i.e. straw of wheat and barley, stem residues of maize and oilseed rape, in a small bio-chemical cycle of field agro-ecosystem is a significant factor of protecting functional stability, whereas fertility of soil can be sustained continuously via appropriate control of its physical-chemical properties and the reaction of the soil solution.

REFERENCES

Akhtar K., Wang W., Khan A., Ren G., Afridi M.Z., Feng Y., Yang G. 2018. *Wheat straw mulching with fertilizer nitrogen: an approach for improving soil water storage and maize crop productivity*. Plant Soil Environ., 64: 330-337. doi.org/10.17221/96/2018-PSE

Akhtara K., Wang W., Ren G., Khand A., Feng Y., Yang G., Wanga H. 2019. *Integrated use of straw mulch with nitrogen fertilizer improves soil functionality and soybean production.* Environ. Int., 132: 105092. doi.org/10.1016/j.envint.2019.105092

Bakht J., Shafi M., Jan M.T., Shah Z. 2009. *Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (Triticum aestivum* L.*) production*. Soil Tillage Res., 104: 233-240. doi.org/10.1016/j.still.2009.02.006

Cerozi BDS., Fitzsimmons K. 2016. *The effect of pH on phosphorus availability and speciation in an aquaponics nutrient solution*. Bioresour. Technol., 219: 778-781. doi.org/10.1016/j.biortech.2016.08.079

Coppens F., Garnier P., De Gryze S., Merckx R., Recous S. 2006. *Soil moisture, carbon and nitrogen dynamics following incorporation and surface application of labelled crop residues in soil columns*. Eur. J Soil Sci., 57(6): 894-905. doi.org/10.1111/j.1365-2389.2006.00783.x

Degodyuk S., Degodyuk E., Litvinova O., Kirichenko A. 2013. *A strategy for the use of straw residues for fertilizers and energy needs in Ukraine*. Bull Lviv Nat Agrar Univ Agronomy, 17: 205-211.

Devau N., Le Cadre E., Hinsinger Ph., Jaillard B., Gerard F. 2009. *Soil pH controls the environmental availability of phosphorus: Experimental and mechanistic modelling approaches*. Appl Geochem, 24(7): 2163-2174. doi.org/10.1016/j.apgeochem.2009.09.020

Hnativ P.S., Lagush N.I., Haskevich O.V. 2019. *Morphological and physicochemical diagnostics of soils*. Lviv: Magnolia-2006, 168 p.

Jokubauskaite I., Karcauskiene D., Antanaitis S., Mazvila J., Slepetiene A., Končius D., Piaulokaite-Motuziene L. 2015. *The distribution of phosphorus forms and fractions in Retisol under different soil liming management*. Zemdirbyste-Agriculture, 102(3): 251-256. doi.org/10.13080/z-a.2015.102.032

Karami A., Homaee M., Afzalinia S., Ruhipour H., Basirat S. 2012. *Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties*. Agric. Ecosyst. Environ., 148: 22-28. doi.org/10.1016/j.agee.2011.10.021

Khan A., Ali N., Haider S.I. 2018. *Maize productivity and soil carbon storage as influenced by wheat residue management*. J. Plant Nutr., 41: 1868-1878. doi.org/10.1080/01904167.2018.1463384

Kraska P. 2012. *Content of some elements in grain of spring wheat cv. Zebra depending on soil tillage systems and catch crops*. J. Elem., 16(3): 407-419. DOI: 10.5601/jelem.2011.16.3.06

Li F.M., Song Q.H., Jjemba P.K., Shi Y.C. 2004. *Dynamics of soil microbial biomass C and soil fertility in cropland mulched with plastic film in a semiarid agro-ecosystem*. J. Soil Biol. Biochem., 36(11): 1893-1902. doi.org/10.1016/j.soilbio.2004.04.040

Liu E .K., Yan C.R., Mei X.R., He W.Q., Bing S.H., Ding L.P., Qin L.,. Shuang L, Fan T.L. 2010. *Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China*. Geoderma, 158: 173-180. doi.org/10.1016/j.geoderma.2010.04.029

Malhi S.S., Nyborg M., Goddard T., Puurveen D. 2011. *Long-term tillage, straw and N rate effects on quantity and quality of organic C and N in a gray Luvisol soil*. Nutr. Cycl. Agroecosyst., 90: 227-241. doi.org/10.1007/s10705-011-9427-3

Mazur G.A. 2008. *Reproduction and regulation of light soil fertility: a monograph*. Kyiv, Agrarian Science, 308 p.

McGrath J.M., Spargo J., Penn C.J. 2014. *Soil fertility and plant nutrition. Encyclopedia of agriculture and food systems*. San Diego, Elsevier., 5:166-184. doi.org/10.1016/B978-0-444--52512-3.00249-7

Nardi S., Morari F., Berti A., Tosoni M., Giardini L. 2004. *Soil organic matter properties after 40 years of different use of organic and mineral fertilisers*. Europ J Agronomy, 21(3): 357-367. doi.org/10.1016/j.eja.2003.10.006

Škarpa P, Hlusek JA. 2012. *Effect of years, fertilization and growing regions on the content and forms of potassium in soil*. J. Elem., 17(2): 305-315. doi:10.5601/jelem.2012.17.2.12

Sienkiewicz S., Żarczyński P., Krzebietke S. 2011. *Effect of land use of fields excluded from cultivation on soil content of available nutrients*. J. Elementol. 16(1): 75-84.

State Standard of Ukraine 4405: 2005. *Soil quality. Determination of mobile phosphorus and potassium compounds by the Kirsanov method in the modification of the NSC IGA*.

State Standard of Ukraine 7862: 2015. *Soil quality. Determination of active acidity*.

State Standard of Ukraine 7863: 2015. *Soil quality. Determination of light hydrolysis nitrogen by the Cornfield method.*

Truskavetsky R.S., Tsapko Y.L. 2016. *Fundamentals of soil fertility management: a monograph.* Kharkiv, FOP, 388 p.

WRB 2015. *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps.* World Soil Resources Report No. 106. Rome, FAO, 2015.

Yakubovskaya V.V., Hnativ P.S., Melnik A.P. 1988. *What does the nutrition balance of plants say?* Agriculture, 3: 10-12.

Zhang P., Chen X., Wei T., Yang, Z., Jia Z., Yang B., Han Q., Ren X. 2016. *Effects of straw incorporation on the soil nutrient contents, enzyme activities, and crop yield in a semiarid region of China.* Soil Tillage Res, 160: 65-72. doi.org/10.1016/j.still.2016.02.006