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Substatiating the Ecological Ways of Potassium Balance Regulating in Soil

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ABSTRACT

The purpose of the researches was to determine how the potassium balance depended on fertilizing system and how it influenced crop productivity. The experimental part of the work was carried out under the conditions of continuous (since 1964) stationary experiment of the Chair of Agrochemistry and Soil Science the basis of which is a 10-field crop rotation deployed in time and space. The soil of the experimental plots is ashed heavy loamy black soil on loess. For simplifying balance calculations, the number of comparable and equal articles in the coming part and in the extracted one was reduced. It was considered that the total potassium amount which came from the atmosphere and with seeds was responsible for erosion losses and those from washing off. The results obtained show that potassium balance and its intensity in every rotation was formed unevenly and depended considerably on the level of its coming together with fertilizers and removing when harvesting. It has been proved that when increasing the used fertilizer dose, the balance volume rises which characterizes potassium circulation size in agrocenosis. The potassium balance data analysis when leaving unmarketable part in the field has displayed that its intensity increases significantly. Leaving the unmarketable part of the harvest in the field balances potassium in the soil significantly without using high mineral fertilizer doses which entails a number of ecological problems. It has been defined that the majority of crop productivity can be observed at a potassium balance of -30 kg (kg per year). Only clover productivity at a more negative potassium balance has decreased which testifies to its wider tolerance zone as to the given nutrient content in the soil compared to other crop rotations.

Keywords: leibig`s law of the minimum, potassium balance, crop productivity, soil degrading, agrocenosis.

INTRODUCTION

Nowadays the problem of soil degrading in the whole world is crucial and has a global significance exceeding local problems. The world`s every community is aware of the problem, but most of them are still moving in the wrong direction. Although the search for new materials for providing a stable development of countries in the sphere of land use is being conducted, the threats of degrading and its potential effects remain unestimated to a considerable degree [Laila and Ali., 2011].

Over many years the enlargement of farmland has in fact become the major measure for produce increasing. When chasing the additional production methods, the soil was cultivated in every available place: on slopes, in conserved zones alongside water bodies and pastures as well as roadsides. The soil quality decreasing processes were especially intensive in the 1990s because of the worsening crisis phenomena in Ukraine`s economy. As a result of finance lack the inculcation of farming systems with contour and meliorative reorganization of the territory was stopped at which farming was conducted with considerable negative balance of organic substance and the main biogenic elements which encurred a loss of 10% of its energy potential [Truskavetsky and Tsapko, 2016].

At the conferance in Uganda, every side involved reached the agreement that nutrition negative balance had to serve as a soil degrading indicator [Bekunda, 2003]. Accepting such an agreement provides evidence of international cooperation significance in the struggle with soil degrading problems and for providing land resources continuous use. The biogenic elements negative balance indicates that plants lose more nutrients than keep those taken up from the soil.

It is known that nutrient balance calculation is important for providing a more important prognosis of plant need for mineral elements and their effective use. Fertilizing crops should be conducted in such a way to avoid the nutrient negative balance, not to worsen the soil fertility and preserve the environment from excessive fertilizer usage. All of that has conditioned the theme of our researches [Srinivasarao et al., 2014].

The problem of potassium balance is crucial to farming and hasn`t been treated completely. As a rule, scientists suggest a full compensation with fertilizers for removing potassium caused by harvest. But this is not required in most cases. First of all, the calculations made on the basis of average indicators as a rule do not correspond to the data of removing under specified conditions especially by potassium friendly crops through tops (sugar beets), stalks (maize) and grain crop straw. A considerable part of plant residue potassium remains in the field until gathered with remarkable differences depending on weather conditions [Blake et al. 1999; Nosko, 2014; Steingrobe and Claasen, 2000].

Continuous field and vegetative experiments by leading scientists have evinced the influence of potassium balance in agrocenosis on zonal soil potassium state and the cultivated crop produce. They have also defined the impact of the plant potassium nutrition level on their potassium content in different ontogenesis periods, have calculated the removal of the element caused by the main crops yield. It has been determined on the data basis that the optimal potassium balance size is defined through agrocenosis productivity and the soil potassium state. Defining nutrient balance in farming allows to define the surplus and deficiency of some plant nutrients for havest formation. The conducting of such researches in dynamics allows developing propositions for the balance planned regulation in specified territories [Gospodarenko, 2015].

The increasing of plant nutrient additional balance must be considered both as improving soil fertility and soil and water bodies' pollution [Gospodarenko, 2015].

The indicator of potassium maximum permissible deficiency (MPD) within one crop rotation depends on its produce as well as its potassium content level in the soil and its share from cation exchange volume (CEV) and the soil granulometric composition. The necessity of potassium fertilizer usage in doses which exceeds the calculated potassium usage on the whole during one rotation appears in the impoverished soils of light granulated composition at planned good harvests. The overwhelming majority of soil conditions do not require full compensation for removing potassium within one crop rotation. Applying the MPD principle set for each separate crop rotation increases and stabilizes the potassium content in the soil [Poliovyy et al., 2021].

Under modern conditions the process of reducing soil fertility in Ukraine`s ecosystem is confirmed by the balance of the main biogenic elements. Since the 1990s nitrogen, phosphorus and potassium negative balance has been formed at an accelerated rate which consitutes 120–130 kg/ha. This negative progress of soil exhaustion is enhanced by soil erosion [Haby et al., 1990, Gospodarenko, 2002].

One of the tasks while creating a rational fertilizing system is reaching a sufficient nutrient balance. In this aspect the data received during continuous stationary experiments with different fertilizing levels are especially valuable in which the balance articles and biofriendly element circulation peculiarities are considered. The data are one of the main components of fertilizer application theory and are necessary for soil fertility prognosing [Gospodarenko, 2002].

MATERIALS AND METHODS

The experimental part of the work has been conducted in the experimental field belonging to The Department of Training and Production at Uman National University of Horticulture (Cherkasy Region, Central Ukraine) under the conditions of continuous (since 1964) stationary experiment of The Chair of Agrochemistry and Soil Science based on the 10-field crop rotation deployed in time and space. Mineral (with using $N_{45}P_{45}K_{45}$; $N_{90}P_{90}K_{90}$ and $N_{135}P_{135}K_{135}$), organic (manure 9 tons; 13,5 tons and 18 tons) as well as organic and mineral (manure 4,5 tons + $N_{22}P_{34}K_{18}$; manure 9 tons + $N_{45}P_{68}K_{36}$; manure 13,5 + $N_{68}P_{101}K_{54}$) fertilizing systems are used in crop rotation. The soil of the experimental plots is ashed heavy loamy black soil on loess. Crop rotation in field crop rotation is as follows: alfalfa – winter wheat – sugar beet – maize for grain – peas – winter wheat – maize for silage – winter wheat – sugar beets – spring barley with undersowing of alfalfa.

Harvesting of grain crops was carried out using continuous segmental direct combining, while the non-marketable portion of the crop was assessed using the trial bundle method followed by determining the grain-to-straw ratio. Harvesting of sugar beet was done manually after mechanized plant undercutting, followed by cleaning and weighing of the roots. The yield of beet tops was calculated in relation to the roots using a sample of 40 plants.

The potassium general forms cotent in single weighing of plant material was defined by means of wet ashing according to MBB 31-497058-019-2005.

The annual potassium balance in the soil was determined as the difference between its input from fertilizers and its removal with the harvest of agricultural crops. To simplify balance calculations the number of comparable and even articles was reduced both in the amount of coming and in that of the extracting. It was considered that the total amount of potassium which comes from the atmosphere as well as together with seeds corresponds to the amount of its losses from erosion and washing off. Due to these simplifications, only the item of input from fertilizers remained in the income part of the balance, while in the expenditure part, there are removals from the marketable and non-marketable parts of the harvest (farm removal).

RESULTS AND DISCUSSIONS

Annually an average of 2.0 kg/ha of potassium comes into soil together with grain material during grain and beet crop rotation as well as 6.1–8.8 kg/ha of potassium comes into soil through atmospheric precipitation. Potassium losses caused by erosion can reach 88 kg/ha (considering the fact that soil losses make up 4 tons/ha annually when containing the gross potassium 2.2%). It is next to impossible to return such an amount of potassium to the soil using fertilizers, it is not expedient either as the black soil itself is ashed and the soil-forming rock contains large supplies of potassium. It is necessary to compensate for the lost moving solutions of potassium and its reserve which is non-exchangeable and inert. In all, these potassium forms make up 10 kg/ha annually of the total annual lost potassium. Potassium losses in black soils as the result of infiltration can constitute 4–8 kg/ha from a soil layer of 110–140 cm annually, but they haven`t been considered due to the lack of sufficient quantity of presentative data [Tkachenko, 2013].

The change of the moving potassium form content in the soils is in certain dependence on their balance condition [Gospodarenko et al., 2013; Karami et al., 2012]. On the whole the optimal balance value is defined by the agrocenosis productivity and the soil potassium condition [Balik et al., 2020]. The results receieved have shown that potassium balance and its intensity (IB) in every rotation have been formed unevenly and depended largely on its coming with fertilizers and its removal caused by harvest.

The calculations of the potassium balance within the last 6 crop rotations have allowed to sum it up depending on the fertilizing systems and levels during a 60-year period (Figure 1).

So, the potassium removal caused by field rotation crops on the plots of land without fertilizers made up 4250 kg/ha. Due to using single doses of fertilizers it has grown 1.3 times and due to using triple doses it has grown 1.5 times with a negative balance. The potassium balance intensity depending on the doses of fertilizers used was within 41–97% using mineral system, 50–75% when using organic system and 39-92% while using the organic and mineral one.

Figure 2 shows the potassium balance volume when using different fertilizing levels in field crop rotation. It is proved that the increased dose of fertilizers used entails the balance volume rises which characterizes the size of potassium circulation in agrocenosis. To our mind the soil plant system openness plays an important role in the change of soil potassium state when nearly the whole soil mass is removed and with it are large potassium amounts including the ones mobilized from the ground reserve. The restoration of potassium forms natural proprtions in the soil especially the reserve ones is possible under the condition of enhanced fixation of the biologically available fertilizer element. Under such conditions the intensifying of potassium fixing ability of the soil reflects the increasing of agrophitocenosis biological productivity. Any distortion of substance balance in the soil when using mineral fertilizers changes the substance energy proportion in the soil-plant and soil-microorganism system [Brouder et al., 2011; Nardi et al., 2004]. Under the conditions of the energetic efficiency, its liquidation occurs through the destruction of organic and mineral substances of the soil which leads to intensifying natural degrading processes connected with plant trophic.

Since the plant vegetative organs are characterized by a higher potassium content than the productive ones, then leaving the unmarketable part of the harvest in the field reduces potassium deficiency significantly. The potassium balance data analysis when

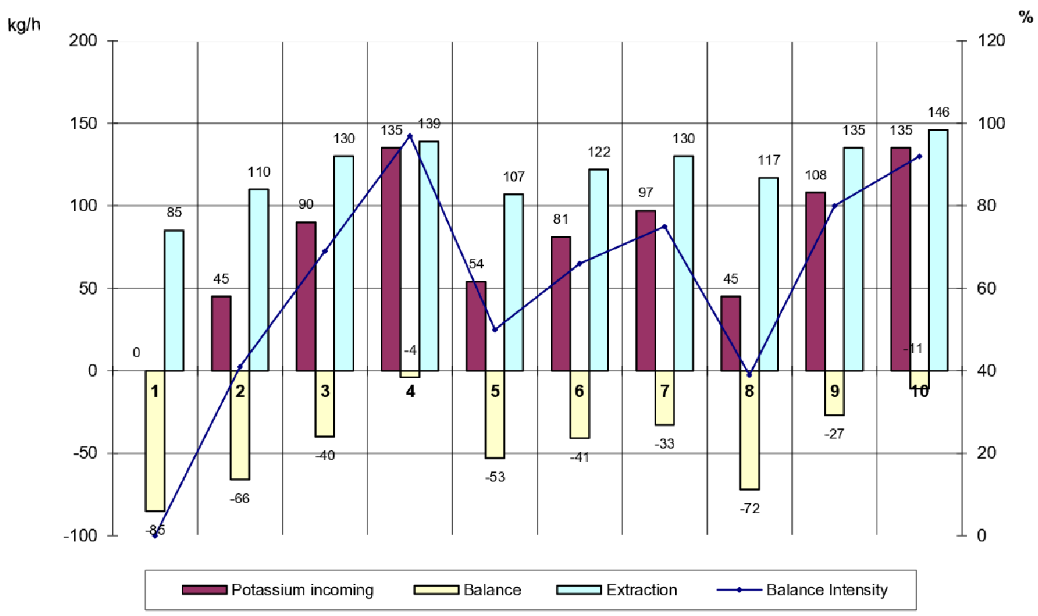

Figure 1. Potassium balance (K_2O) in the crop rotation soil (1964–2019) and its intensity when using different fertilizers in crop rotation: 1) without fertilizers (control); 2) $N_{45}P_{45}K_{45}$; 3) $N_{90}P_{90}K_{90}$; 4) $N_{135}P_{135}K_{135}$; 5) Manure 9 tons; 6) Manure 13,5 tons; 7) Manure 18 tons; 8) Manure 4,5 tons + $N_{22}P_{34}K_{18}$; 9) Manure 9 tons + $N_{45}P_{68}K_{36}$; 10) Manure 13,5 tons + $N_{68}P_{101}K_{54}$

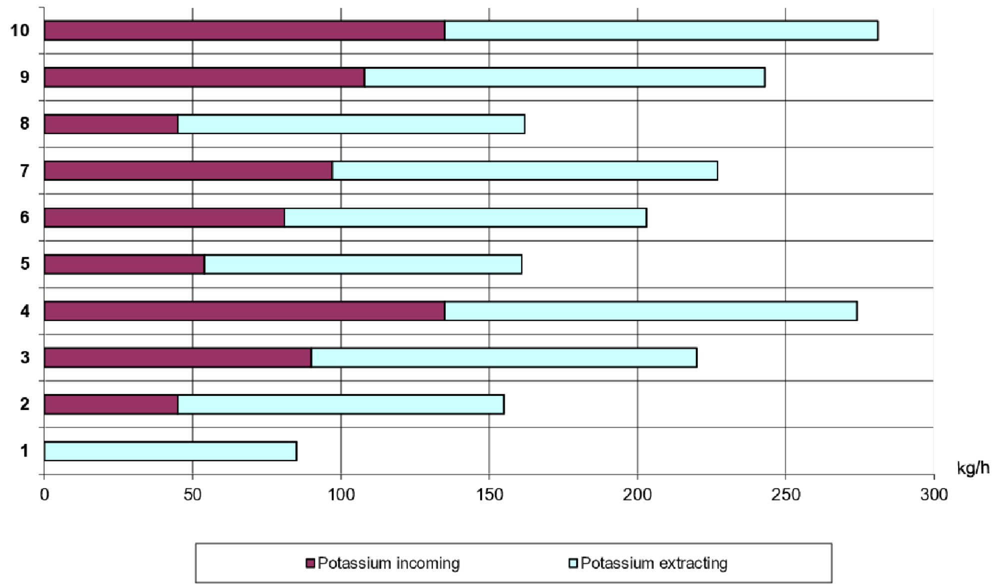

Figure 2. The potassium balance volume in the soil at continuous (1964-2019) usage of fertilizers in a field crop rotation: 1) Without fertilizers (control); 2) $N_{45}P_{45}K_{45}$; 3) $N_{90}P_{90}$K90; 4) $N_{135}P_{135}K_{135}$; 5) Manure 9 tons; 6) Manure 13,5 tons; 7) Manure 18 tons; 8) Manure 4,5 tons + $N_{22}P_{34}K_{18}$; 9) Manure 9 tons + $N_{45}P_{68}K_{36}$; 10) Manure 13,5 tons + $N_{68}P_{101}K_{54}$

leaving the unmarketable part in the field, has evinced that its intensity rises largely (Figure 3). So, the balance in the experiment variant without using fertilizers has made up 37 kg/ha only, which is considerably smaller than the analogical indicator under the condition of extracting the unmarketable part of the harvest from the field. Here the application of potassium fertilizers in a dose of 45 kg/ha of active substance a year provided 94% of potassium compensation. When doubling the dose of fertilizers its additional balance was made up with the intensity which was 61% more than in the case of using single fertilizer doses and 86% more concerning the analogical indicator under the condition of extracting the unmarketable harvest part. When using potassium together with mineral fertilizers in an amount of 135 kg/ha a year it returning to the ground exceeded its removal by 71 kg/ha a year, and the balance intensity constituted 211%.

So, the potassium balance in soil was defined by potassium application level and removing potassium by rotation crops and by unmarketable part of the harvest. The potassium fertilizer application in a dose of 45–135 kg/ha of the active substance for 60 years didn't provide potassium additional balance in the soil. An average of 48 kg/ha of K_2O or 56% from its removal through farming are extracted by the unmarketable harvest part on the land plots without fertilizers a year. As for the experiment $N_{135}P_{135}K_{135}$ this share almost hasn`t changed (54%). It testifies that under the condition of leaving the unmarketable part of the harvest in the field as fertilizer, the soil potassium balance can be improved significantly and potassium application dose in crop rotation can be diminished by half. Sustaining the indicators of potassium regime in optimal limits when using the soil in the system of intensive farming can be carried out by means of returning the unmarketable harvest part to the soil [Nikitina and Vasylenko, 2019, Liu et al., 2010].

Science and advanced experience have proved that for growing good harvests of agricultural crops the main nutrients should be put into soil significantly more than they are used by plants to form harvest [Cakmak, 2010; Truskavetsky and Tsapko, 2016]. We have analized productivity losses of field rotation crops under the condition of different potassium balance in the soil. Taking into consideration Figure 4 one can draw a conclusion that the productivity of every crop that is

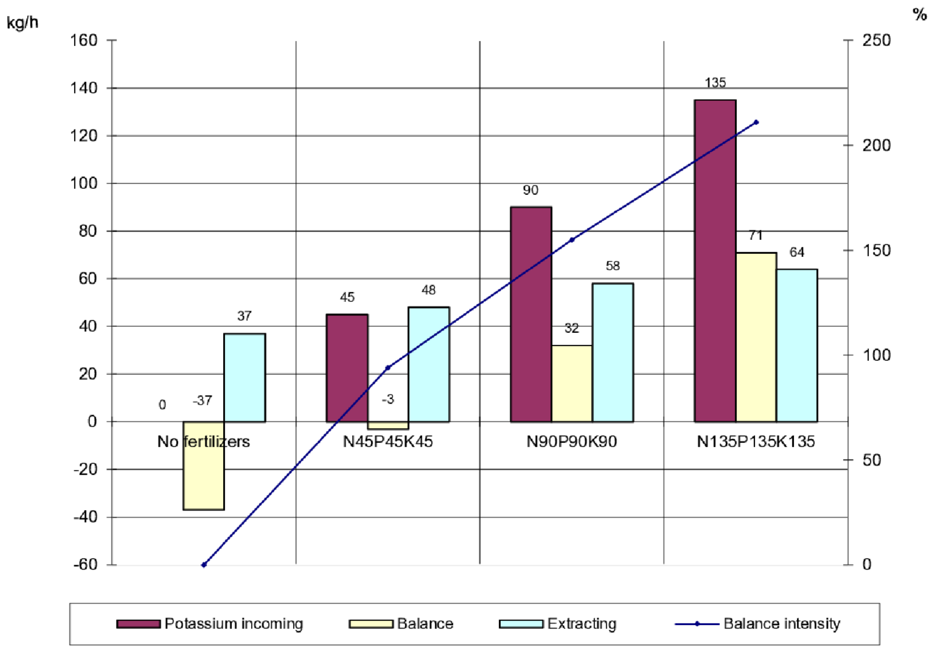

Figure 3. Potassium (K_2O) balance in the soil of field crop rotation and its balance at different fertilizing when leaving unmarketable part of harvest in the field, yrs 1965–2019.

cultivated in the rotation is reduced when potassium balance is less than -30 kg (kg/year). Lesser clover productivity was caused by the balance lower than -80 kg (ha/year).

The permissible potassium balance deficit with 40-80% intensity provides applying 45–90 kg of K_2O/ha of crop rotation square in field crop rotation in black ashed soil in Central Ukraine. In case of leaving unmarketable harvest part in the field potassium fertilizer dose mustn`t exceed 45 kg/ha of active sustance. Acceptibility and justification of low-deficient potassium balance in crop rotation has been indicated earlier [Egner et al., 1960; Truskavetsky and Tsapko 2016]. In dynamics potassium fertilizer dose should be defined by crop rotation productivity and soil potassium state.

The main factor leading to a decrease in fertilizer usage in Ukrainian agriculture and their low efficiency was insufficiently considered socio-economic changes in the country. The second reason for this phenomenon is the erroneous assessment of soil fertility, irrational fertilization systems, and consequently, low returns from the application of expensive fertilizers and a decrease in demand for them [Khrystenko, 2014]. In this regard, the least attention is paid to regulating potassium levels in agrocenoses. Potassium fertilizers are often not applied, and the element's balance remains consistently deficient. Obviously, there is a disregard for important ecological laws – the equivalence and indispensability of plant life factors, the return of potassium minimum, which can undoubtedly negatively affect the agrochemical and ecological condition of soils [Yaroshko, 2013]. The situation worsened after a recent increase in prices for potassium fertilizers. Therefore, the research presented in this article is quite relevant, as it provides the results of studies on the impact of different fertilization systems on soil potassium balance and the influence of using non-marketable parts of the harvest as fertilizer.

Until now, it is still believed that potassium reserves in the soil are inexhaustible [Lisovyi and Nikitiuk, 2006; Nosko and Hladkikh, 2012]. However, intensive agricultural use of soils, including typical black soil, without the application of fertilizers against a negative balance leads to a decrease in the content of all forms of potassium, indicating a close relationship between the processes of transformation of the potassium fund after plowing the virgin soil.

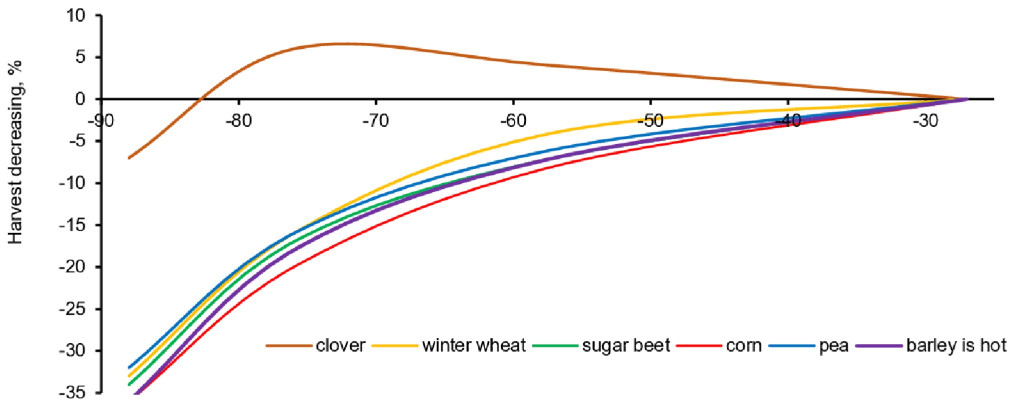

Figure 4. Lesser harvest of agricultural crops caused by different potassium balance in crop rotation

When organic waste is properly and fully utilized, potassium returns to the soil in greater quantities than nitrogen and phosphorus. However, to create optimal potassium nutrition for plants with high nitrogen and phosphorus nutrition, it is usually necessary to apply industrial potassium fertilizers to the soil [Kryvov, 2006]. The application of mineral fertilizers from an environmental point of view can cause environmental pollution, as adverse weather conditions can often affect the intensity of plant nutrient uptake or lead to their leaching beyond the field boundaries. Therefore, this emphasizes the importance of exploring alternative options for returning the potassium component to the soil.

The possibility of applying potassium fertilizers «in reserve» has been proven. However, from ecological and economic considerations, it is advisable to avoid single applications of excessively high doses of potassium fertilizers because this leads to the irreversible fixation of potassium, disrupts the Ca: (Na+K) ratio, which accelerates the replacement of divalent cations in the soil absorbing complex (SAC) with monovalent ones, and deteriorates the physical and chemical properties of the soil [Prymak et al., 2010].

In practice, the nutritional needs of plants are usually determined taking into account their uptake. This considers the amount of nutrients removed from the soil with the harvested crop. Economic removal is significantly less than the biological demand of plants for nutrients during the growing season, as a significant portion of them moves and accumulates in varying quantities in the yield, post-harvest residues, and root system. [Gospodarenko, 2002].

The potassium content in plants depends on the biological and varietal characteristics of crops, soil-climatic conditions, fertilizer application rates, and other factors and is not a constant value. Therefore, scientists do not have a unanimous opinion on the potassium content in plants. Some believe that increasing doses of mineral fertilizers increase potassium content and decrease dry matter content [Zubkovska, 2015]. Others suggest that significant changes in potassium content in plant dry matter do not occur under the influence of fertilizers [Smirnova, 2015].

Depending on the type of agricultural crop, potassium consumption varies significantly [Pettigrew et al., 2005]. Potassium consumption increases with higher yields due to the growth and development of vegetative mass [Nosko, 2014]. Therefore, with increasing yields, more potassium is extracted from the soil, which needs to be replenished. This is confirmed by the results of our research on the potassium balance capacity in the soil.

It should be noted that in the total potassium uptake by crops for primary (marketable) products, a smaller amount of this element is accounted for compared to the non-marketable part of the yield. Therefore, the method of using the non-marketable part of the production (especially straw) for the potassium regime in the agrocenosis is of obvious importance: depending on whether plant residues are left in the field or removed, the potassium balance can noticeably change. Additionally, the structure of the crop (the ratio of marketable and non-marketable parts of the yield) and the timing of harvest (the earlier, the higher the relative potassium content in the non-marketable part of the yield) are important [Poliovyy et al., 2022].

CONCLUSIONS

So, one can draw a conclusion that since the unmarketable harvest part is characterized by high potassium content then leaving it in the field compensates for potassium deficit. Here it is possible to balance potassium in the soil without using high doses of mineral fertilizers which incurs a number of ecological problems. The researches have determined that when using vegetative plant parts for fertilizing soil, using potassium fertilizers can be reduced by half. In case of leaving unmarketable harvest part in the field, potassium fertilizer dose mustn`t exceed 45 kg/ha of active substance.

Rotation crop harvest losses analysis shows that the majority of crop productivity can already be observed when potassium balance is -30 kg (kg/year). The clover productivity only has decreased because of negative potassium balance that is evidence of its wide tolerance zone as to the given nutrient content in the soil compared to other rotation crops. The conclusion gets its confirmation in Leibig`s law of the minimum according to which plant growing depends on the substance, the concentration of which is minimal as well as advanced research analysis which have proved that for gathering good and stable harvests of agricultural crops one must apply a lot more biogenic nutrients than they are used by plants.

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