EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(2), 70–77
https://doi.org/10.12912/27197050/144957
ISSN 2719-7050, License CC-BY 4.0

Received: 2021.11.17
Accepted: 2022.01.13
Published: 2022.02.01

Nutrient Balance of Sod–Podzolic Soil Depending on the Productivity of Meadow Agrophytocenosis and Fertilization

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ABSTRACT

The influence of mineral fertilizers on productivity and nutrient balance of sod–podzolic soil when growing cereal meadow agrophytocenosis under conditions of Precarpathians of Ukraine was researched. It was found that the dependence of cereal agrocenosis productivity on the doses and ratios of N, P, K in mineral fertilizers is described by equation (polynomial) of the 2nd degree. Among the mineral elements, nitrogen is has the greatest influence on grass productivity. When applying the total dose of N_{75} with even distribution of nitrogen under each of three mowings on different backgrounds of phosphorus-potassium fertilizers, the productivity of cereal grass increases by 2.82–3.06 t ha^{-1} of dry mass, and when applying N_{150} by 3.33–4.93 t ha^{-1} of dry mass. Recoupment of nitrogen fertilizers per 1 kg by yield increase when applying N_{75} is 38–41 kg of dry mass, which is 4–5 kg more compared to the application of $N_{150.}$ The indices of phosphorus and especially potassium removal, as well as deficiency of these elements in the balance increased along with nitrogen dose. Independently of the phosphorus and potassium doses, the lowest indices are fixed on a nitrogen–free background, and the highest – on the background of N_{150}.

Keywords: cereal grasses, mineral fertilizers, productivity, sod–podzolic soil, nutrient balance.

INTRODUCTION

An important role in increasing the production of cheap grass fodder belongs to intensification of meadow fodder production by creating sown cereal meadow grasses of intensive type, which are a reliable measure of increasing productivity of meadow lands by 1.5–2.0 times and significant improvement of fodder quality compared to traditional one–, and two–time mowing usage. [Kurhak, 2010; Karbivska et al. 2020; Novák et al. 2020].

Such grasses are created with introduction of complete mineral fertilizers. These fertilizers are highly effective on sufficiently moist lands (floodplain and lowland meadows, normal land and irrigated areas of meadows), predominated by valuable meadow grasses from the group of mesophytes. They increase productivity of lands by 2–3 times and the share of fodder-valuable species in natural grasslands, as it is noted by Makarenko, Bogovin, Kurgak [Kurhak & Karbivska, 2019; Karpenko et al. 2020].

Fertilizer application is one of the most effective measures of haymaking improvement. Under its influence, targeted changes take place under the conditions of meadow plant growing, which lead to domination of valuable species of cereal grasses [Teberdyev & Rodyonova, 2015; Demydas et al. 2021; Nan et al. 2019]. Application of mineral fertilizers in meadows in optimal doses and ratios not only increases the productivity, but also has a beneficial effect on the chemical composition of fodders [Karbivska et al. 2019; Chețan et al. 2021; Litvinov et al. 2020].

The countries of Western Europe prefer nitrogen fertilizers with its application in doses up to 300 kg or more per ha, where its application is effective [Carisson & Huss-Daneli, 2003; Kurgak & Tovstoshkur 2008; Tonkha et al. 2021]. Numerous studies in Eastern Europe and Ukraine have also identified the possibility of sharp increase in productivity of cereal meadow grasslands with application of increased nitrogen fertilizer doses (60–300 t ha^{-1}) on different types of land [Kurhak, 2010; Yakupoglu et al. 2021; Kurhak et al. 2018].

The efficiency of nitrogen fertilizers largely depends on the composition of grassland, as each species has its own reaction to nitrogen and its own ecological and synecological optimum. These species characteristics of grasses are especially clear in relation to nitrogen, which is confirmed by the results of research in Ukraine [Yarmoliuk et al. 2013; Ivanova et al. 2021; Kvitko et al. 2021]. The return from nitrogen fertilizers is greater on grasslands with a predominance of highland cereal species over lowland and low–value wild species. The greatest return in cereal grasslands is provided by complete mineral fertilizer, followed by, in descending order, nitrogen-potassium, nitrogen–phosphorus, nitrogen, potassium–phosphorus, potassium and phosphorus fertilizers [Yarmoliuk et al. 2013; Danilchenko et al. 2018; Mischenko et al. 2017].

Inevitability of wide human intervention into environment requires such a direction of economic activity which would create artificial balance in the nature. The ultimate goal of such usage is a combination of maximum return, preservation of soil fertility and improvement of the ecological conditions of territories [Hospodarenko & Gherno, 2015; Dehodiuk & Litvinova, 2009; Shtakal, 2019; Mischenko et al. 2019].

The study of nutrient balance is one of main problems of agrochemistry. It is connected with the need for systematical improvement of effective soil fertility, crop yielding capacity and quality of obtained products. Balance of nutrients helps to establish their removal from soil by the harvest and entry into the soil from various sources. If consumption of nutrients due to their removal with the harvest is not compensated by the application of fertilizers, then gradual depletion of the soil and reduction of yields takes place [Datko, 2008; Litke et al. 2019; Moldovan et al. 2018; Tanchyk et al. 2021].

Despite significant amount of research on fertilizer dose study, until recently, the experimental data on the usage of modern methods of planning and modeling experiments with fertilizers on natural fodder lands under the conditions of Precarpathians are not sufficient, that is why these issues were the purpose of the conducted research.

MATERIAL AND METHODS

Experimental studies were conducted on experimental field of Agrochemistry and Soil Science Department at Dendrological Park "Druzhba" SHEI "Vasyl Stefanyk Precarpathian National University". The experiment was conducted on cereal grassland, which was formed on the basis of grass mixture (*Lolium pratense*, 8 kg ha^{-1} + *Phléum praténse*, 6 kg ha^{-1} + *Bromus inermis*, 12 kg ha^{-1}) as three-factor, using the possibilities of mathematical planning method of the experiment, by d–optimal shortened scheme, where each mineral element of fertilizers is a factor, and fertilizer doses are parameters at three levels. For the study, 15 variants of fertilizers were taken instead of 27, so that the experiment was full–factor. The experiment was carried out in 2016, while records and observations were conducted over 2017–2019.

The area of sowing plots was 15 m^2, accounting – 10 m^2. The experiment was repeated four times. Phosphorus–potassium fertilizers were applied annually superficially in early spring, and nitrogen – in three motions: N_{25} and N_{150} in spring on frost–melting soil and after the first and second mowing. The following types of fertilizers were used in the experiment: nitrogen – ammonium nitrate (34%), potassium – potassium and magnesium sulfate (26%), phosphorus – simple superphosphate (18.7%).

The scheme of experiment included the following variants: Factor A – grass mixture: Phléum praténse, Lolium pratense, Bromus inermis. Factor B – fertilization: 1. Control (without fertilizers); 2. P_{60}; 3. K_{90}; 4. $P_{60}K_{90}$, 5. N_{75}; 6. $N_{75}P_{60}K_{90}$; 7. N_{150}; 8. $N_{150}P_{60}K_{90.}$

The soil of experimental plots is sod–podzolic, superficially gleyed on alluvial–dealluvial deposits. The pH of soil solution is strongly acidic (pH – 4.6). Humus content in the 0–20 cm layer is 2.1%. The arable soil layer contained movable forms of nutrients, on average: movable phosphorus (67.3 mg kg^{-1} of soil) and potassium (96.8 mg kg^{-1} of soil), according to Kirsanov.

Weather and climatic conditions in the years of research differed slightly from average long-term indices both in terms of precipitation and values of average daily temperatures. Thus, average daily air temperature during the growing season of 2017 exceeded the average long-term value (+ 15.3°C) by 0.8°C. In 2018, amount of precipitation was insufficient, by 93.6 mm less than average long–term index that negatively affected re–growing of grasses in aftermaths.

The study was conducted according to the methodology of the Institute of Fodders and Agriculture of Podillya NAAS [Babych, 1994]. The balance of nitrogen, phosphorus and potassium in the soil was determined by the difference between the total amount of each element that entered the soil with fertilizers, precipitation and its alienation with the crop [Datko, 2008]. Mathematical processing of research results was conducted by methods of disperse analysis and variation statistics, according to Dospekhov on a personal computer using program Statistica 6 [Dospekhov, 1985].

RESULTS AND DISCUSSION

The analysis of study results concerning the influence of doses and ratios of NPK in mineral fertilizers on productivity showed that the most effective mineral nutrient on the sown cereal grassland: *Phléum praténse, Lolium pratense, Bromus inermis*, was nitrogen (Fig. 1). It was determined that the application of nitrogen dose of N_{75} with distribution of 25 kg. a.s. of phosphorus–potassium fertilizers for each of three mowings on different backgrounds increased the cereal grass productivity on average from 2.53–3.47 t ha^{-1} to 5.35–6.53 t ha^{-1} of dry mass, and application of $N_{150\ (50+50+50)}$ – up to 7.46–8.80 t ha^{-1}, respectively. Thus, the highest productivity of grass fodder was obtained with application of N_{150}.

However, recoupment of 1 kg of nitrogen fertilizer by the yield of dry mass was higher with application of $N_{75.}$ With application of this dose, recoupment of 1 kg of nitrogen fertilizers in dry mass was 38–41 kg, which is 4–5 kg more compared to the application of nitrogen dose N_{150}.

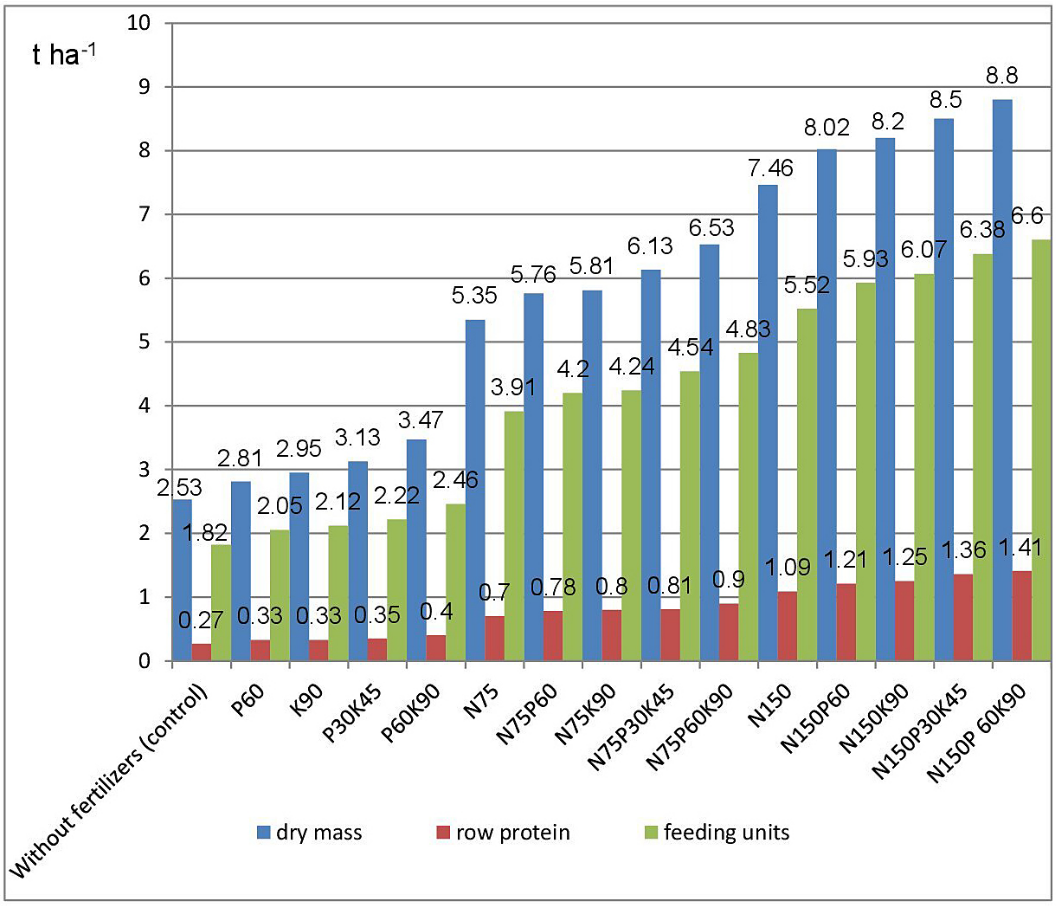

Figure 1. Influence of doses and ratios of NPK fertilizers on productivity of cereal grassland (average for 2017–2019)

Phosphorus and potassium fertilizers had much less effecter on the productivity of sown cereal grassland. Yield increase with the application of phosphorus dose P_{60} on different nitrogen backgrounds ranged from 0.28 to 0.56 t ha^{-1} with recoupment 5–9 kg of dry mass per 1 kg of active substance.

With the application of potassium dose K_{90} on different nitrogen backgrounds, this index was equal to 0.42–0.74 t ha^{-1} with recoupment 5–8 kg of dry mass per 1 kg of active substance. With combined application of phosphorus and potassium in full and half doses on different nitrogen backgrounds, the productivity of sown grassland increased by 0.60–1.34 t ha^{-1} of dry mass with recoupment from 6 to 14 kg per 1 kg of their active substance.

Slightly larger increases in the dry mass yield from application of phosphorus and potassium fertilizers and dry mass recoupment per 1 kg of these fertilizers were obtained on the background of nitrogen fertilizer application. In most cases, these indices increased along with the doses of nitrogen fertilizers.

A positive effect of phosphorus and potassium fertilizer interaction was also observed, especially on the background of nitrogen application in different doses. Recoupment of dry mass yield per 1 kg of combined application of phosphorus and potassium fertilizers with application of $P_{30}K_{45}$ was slightly higher, compared to the dose of $P_{60}K_{90}$.

Intermediate recoupment between the application of only nitrogen fertilizers or only phosphorus and potassium fertilizers showed their joint application. In this case, recoupment per 1 kg of fertilizer active substance ranged from 18 to 27 kg. Slightly higher indices of fertilizer recoupment were obtained under conditions of joint application of nitrogen with phosphorus and potassium in a dose of N_{150}, than in a dose of N_{75}.

The highest productivity was in the case of combined application in maximum studied doses $N_{150}P_{60}K_{90}$. In this case, the yield of dry mass from 1 ha was 8.80 t ha^{-1}, which is 3.5 times more than in the variant without fertilizers.

Productivity also changed markedly over the years of using sown cereals. It was the highest in 2017 – the first year of using grassland and the second year of grass life. That year, the yield of dry mass from 1 ha on different fertilizer variants ranged from 2.71 to 9.28 tons, which is 1.1 times more than in 2019, where it ranged from 2.30 to 8.38 t ha^{-1}. The obtained regularity of sown cereal grassland productivity depending on doses and ratios of NPK by the outcome of dry mass from 1 hectare was the same as outcome of dry mass of crude protein, fodder units and exchange energy from 1 hectare of dry mass.

On the same phosphorus-potassium backgrounds, the highest productivity by these indices was shown in the variant of application N_{150}.

Table 1. Distribution of dry mass yield by mowings of cereal grassland depending on the variants of fertilization, average for 2017–2019

Fertilization	T ha^{-1}			%			V, %
	1st moving	2d moving	3d moving	1st moving	2d moving	3d moving	
Without fertilizers (control)	1.01	0.96	0.56	40	38	22	30
P_{60}	1.12	1.10	0.59	40	39	21	31
K_{90}	1.21	1.12	0.62	41	38	21	30
$P_{30}K_{45}$	1.25	1.22	0.66	40	39	21	30
$P_{60}K_{90}$	1.39	1.35	0.73	40	39	21	31
N_{75}	1.97	1.82	1.56	37	34	29	10
$N_{75}P_{60}$	2.07	1.90	1.79	36	33	31	11
$N_{75}K_{90}$	2.09	1.92	1.80	36	33	31	12
$N_{75}P_{30}K_{45}$	2.21	2.02	1.90	36	33	31	13
$N_{75}P_{60}K_{90}$	2.35	2.15	2.03	36	33	31	12
N_{150}	2.61	2.54	2.31	35	34	31	7
$N_{150}P_{60}$	2.81	2.65	2.56	35	33	32	5
$N_{150}K_{90}$	2.87	2.64	2.69	35	33	32	7
$N_{150}P_{30}K_{45}$	2.98	2.81	2.71	35	33	32	5
$N_{150}P_{60}K_{90}$	3.08	2.82	2.90	35	33	32	5
LSD_{05}	0.17	0.15	0.14	–	–	–	–

Note: V, % – distribution irregularity of the yield by mowings, expressed by variation coefficient.

The yield of crude protein from 1 ha in this case in different variants of phosphorus and potassium fertilizer application for three years of research increased on average from 0.27–0.40 to 1.09–1.41 t ha^{-1}, feeding units – from 1.82–2.46 to 5.52–6.60 t ha^{-1}, exchange energy – from 20.4–28.1 to 61.2–73.0 GJ ha^{-1}.

With the application of N_{75}, the yield of crude protein from 1 ha for different variants of phosphorus and potassium fertilizers increased to 0.70–0.90 t ha^{-1} or by 2.3–2.6 times, feeding units – up to 3.91–4.83 t ha^{-1} or by 1.9–2.1 times, exchange energy – up to 43.3–53.5 GJ ha^{-1} or by 1.9 times.

The highest productivity in terms of nutrient yield as well as in terms of dry mass outcome from 1 ha was in the case of applying the maximum studied doses of fertilizers, namely $N_{150}P_{60}K_{90}$. In this case, the yield of crude protein from 1 ha was 1.41 t ha^{-1}, which is 5.2 times more than the variant without fertilizers, feeding units – 6.60 t ha^{-1} and exchange energy – 73.0 GJ ha^{-1}, which is 3.6 times greater compared to the same variant without fertilizers.

With the application of nitrogen fertilizers, the productivity in each mowing as well as the uniformity of yield distribution by the same mowings were significantly improved. In the experiment of studying the doses and ratios of NPK in mineral fertilizers, the most uniform distribution of the yield by mowings was obtained in the variants with the application of nitrogen in a dose of N_{150} (Table 1). In this case, distribution irregularity of the yield by mowings, expressed by variation coefficient, was 5–7%.

The share of the 1st mowing was 35%, the 2nd – 33–34%, the 3rd – 31–32%. With the application of N_{75} the distribution irregularity of the yield by mowings with different doses of phosphorus and potassium was at the level of 10–13%. In this case, the share of the 1st mowing was in the range of 36–37%, the second – 33–34% and the 3rd – 31–32%. On different backgrounds of phosphorus and potassium application, the least uniform distribution of the yield by mowings was in the variant without nitrogen fertilizers.

In these variants of the experiment, distribution irregularity of the yield by mowings was 30–31% with the share of the 1st mowing 40–41%, the second – 38–39% and the 3rd – 21–22%. Application of nitrogen fertilizers in a dose of N_{75}, compared to the control (without fertilizers), reduces the distribution irregularity of the yield by mowings by 17–20%, and application of N_{180} – by 23–26%.

The analysis of absolute productivity indices by mowings showed that regularity traced in general in all mowings also remained in each mowing. It was the highest in all mowings with the application of N_{50} under each mowing. The yield of dry mass from 1 ha in this case increased in the 1st mowing from 1.01–1.39 to 2.61–3.08 tons, in the 2nd – from 0.96–1.35 to 2.54–2.82 tons and in the 3d – from 0.56–0.73 to 2.31–2.90 tons, respectively, and by 2.2–2.5, 2.1–2.6 and 4.0–4.1 times more compared to the variant without fertilizers.

With application of N_{25} under each mowing the yield of dry mass from 1 ha increased by the mowings, respectively, to 1.97–2.35, 1.82–2.15 and 1.56–2.03 tons, and by 1.7–2.0, 1.6–1.9 and 2.8 times compared to the variant without fertilizer.

Thus, the largest increase of productivity from application of nitrogen fertilizers was recorded in the third mowing, which is stipulated by much worse regrowth of grasses in aftermaths in the variants without nitrogen application, compared to the ones with nitrogen application.

Regardless of fertilizer variants, the highest productivity was obtained in the first mowing and the lowest - in the third. However, this difference between the 1st and 3rd mowings varied depending on fertilizer variants. The greatest difference between the 1st and 3rd mowing was in the variants without nitrogen fertilizers, where the yield of dry mass from 1 ha in the first mowing was 1.01–1.39 t, which is 1.8–1.9 times more compared to the third one. In the variants with application of nitrogen fertilizers in a dose of N_{25} the yield of dry mass from 1 ha in the first mowing was 1.97–2.35 t, and with application of N_{50} – 2.61–3.08, which is 1.1–1.3 times more compared to the third mowing, the second mowing occupied intermediate place in terms of productivity.

When growing cereal grasses, depending on doses and ratios of NPK fertilizers on sod–podzolic soils, on average for 2017–2019, in most variants, the balance was negative with a deficit from 2 to 38 kg ha^{-1} (Fig. 2).

Exceptions were the variants with nitrogen application, where positive balance was observed: with application of N_{75} 1 kg t ha^{-1}, and N_{150} – 14 kg ha^{-1}, which is stipulated by lower removal with the harvest compared to application of nitrogen in combination with phosphorus-potassium fertilizers. Regardless of nitrogen dose, its greatest

Figure 2. Balance of nitrogen, P2O5 and K2O in the system "plant-fertilizer" for growing cereal grasses depending on doses and ratios of NPK fertilizers, average for 2017–2019, kg ha-1

deficiency was found in the variants with combined application of phosphorus and potassium in doses of $P_{60}K_{90}$. In the variant with $P_{60}K_{90}$, the nitrogen deficit was – 26 kg ha^{-1}, $N_{75}P_{60}K_{90}$ – 31 kg ha^{-1}, and $N_{150}P_{60}K_{90}$ – 38 kg ha^{-1}. With the application of only P_{60}, or K_{90}, or $P_{30}K_{45}$ nitrogen deficiency was intermediate between the control and the variant with application of $P_{60}K_{90}$.

The balance of P_2O_5 for growing mixture of cereal grasses showed that the variants with phosphorus fertilizer were positive with indices of 2–50 kg ha^{-1}, which is stipulated by small removals of phosphorus (10–31 kg ha^{-1}) with the harvest (Fig. 2).

Negative balance of phosphorus on the studied grassland was in the variants without phosphorus application, with deficiency ranging from (–8) to (–26) kg ha^{-1}. The lowest phosphorus deficiency was on the background without nitrogen application with indices (–8) – (–10), and the highest – N_{150} with parameters – (–23) – (–26). The indices of phosphorus deficiency on the background of N_{75} application in this case were average.

In contrast to phosphorus, the potassium balance in the studied grassland was negative with a deficiency range from (–1) to (–169) kg ha^{-1}, which is caused by too significant parameters of potassium removal with the harvest, which ranged from 61 to 200 kg ha^{-1}. The exception was the variant with K_{90}, where potassium balance was positive (12 kg ha^{-1}). Slight potassium deficiency (–1 kg) was registered in the variant with $P_{60}K_{90}$. The largest potassium deficiency (–169 kg ha^{-1}) was in the variant with application of $N_{150}P_{60}$.

CONCLUSIONS

Dependence of cereal grassland productivity for growing on sod–podzolic soil on doses and ratios of N, P, K in mineral fertilizers is described by the equation (polynomial) of the second degree. The most effective nutrient affecting productivity of cereal grasses is nitrogen. With application of $P_{60}K_{60}$, the productivity, compared to the variant without fertilizers, increases by 3–23%, N_{75} on different backgrounds of phosphorus and potassium – by 1.8–2.1 times, N_{150} – by 2.5–2.9 times with recoupment per 1 kg of fertilizer active substance, respectively – 5–14, 38–41 and 33–36 kg of grass fodder dry mass. Recoupment per 1 kg of nitrogen by yield increase is higher with the application of N_{75} and is 38–41 kg of dry mass, which is 4–5 kg greater compared to the application of N_{150}.

The removal indices of phosphorus and especially potassium, as well as deficiency of these elements in the balance increased along with the dose of nitrogen. Regardless of the phosphorus and potassium doses, the lowest values were recorded on a nitrogen–free background, and the highest – on the background with application of N_{150}.

Therefore, it is necessary to apply mineral fertilizers for cereal grasses which increase grassland productivity and fertility of sod–podzolic soil.

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