

PHOSPHORUS, POTASSIUM, AND PH VALUES IN THE GRASSLAND SOILS  
AND THE RECOMMENDATIONS FOR THE IMPROVEMENT OF SOIL NUTRIENT  
CONTENT IN THE POMURJE REGIONSADRŽAJ FOSFORA I KALIJA I PH VRIJEDNOST U TLIMA TRAVNJAKA TE  
PREPORUKE ZA POBOLJŠANJE SADRŽAJA HRANIVA U TLIMA NA PODRUČJU  
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## SUMMARY

For the sake of an analysis of phosphorus, potassium, and soil pH values in the air-dried soil samples, 1,350 grassland soil samples were examined for the period from 2009 to 2014, and 550 soil samples were examined for the period from 2015 to 2019. In both studied periods, the phosphorus content averagely ranged between 10.14 and 11.17 mg P<sub>2</sub>O<sub>5</sub>/100 g or reached the B level of supply, according to Mirko Leskošek's (1993) recommendations. In the first period studied, the potassium content in the soil reached an average of 15.86 mg K<sub>2</sub>O/ 100 g of soil and an average of 15.37 mg K<sub>2</sub>O/ 100 g of soil in the second period studied, having reached the B level of supply. During the periods studied, the pH value reached a value of an explicitly acidic reaction, or an average pH value of 5. Based on the results obtained, general recommendations for grassland fertilization and calcification were prepared.

Keywords: chemical analysis of soil, grassland, phosphorus, potassium, pH value, recommendations for fertilizer application

## 1. INTRODUCTION

In northeastern Slovenia, in the Pomurje region, there are 22,000 hectares of grassland. These are mainly absolute grasslands that cannot be plowed due to natural conditions.

Phosphorus and potassium are among the most important plant macronutrients, so understanding their dynamics in the soil and their physiological significance in plants is extremely important for agricultural practice. Grassland requires many nu-

trients to grow, but they must be in a certain ratio. Phosphorus and potassium are the essential minerals and are also very important in livestock farming and milk and meat production.

Nyle Brady and Ray Weil (2008) state that soil acidity, or the soil pH value, is one of the essential soil properties that affects both physicochemical processes in the soil (i.e., the availability of plant nutrients and the accumulation of toxic substances in the plant), as well as the physiological processes in plants.

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Readily available phosphorus and readily available potassium is that part of a total content of these two elements that is detected in a soil solution or is adsorbed in the soil colloids as an exchangeable ion and, as such, is available to the plants, being the so-called plant-available phosphorus and potassium (Zupan et al. 2018).

Branko Kramberger (1995) states that if a sufficient amount of a plant-available nutrient is present in the soil, a high content of this nutrient in the herbage can also be expected, but that is not a condition, as the uptake thereof may be hindered due to a lack, or due to an excessive amount of, another plant-available nutrient.

As stated by Nicolas Aubertin and associates (2024), the elevated levels of phosphorus in the environment can cause certain effects, for instance an increased algal growth in water. Some EU countries have therefore already adopted the regulations regarding phosphorus input into soil. The soil pH value plays an important role in the determination of biological chemical properties.

As stated by Marko Zupan and associates (2018), phosphorus is relatively readily available in neutral and slightly acidic soils. In strongly acidic soils, it is difficult to be accessed, because it binds with the free iron and aluminum cations into insoluble phosphates, while it can bind into the more difficultly accessible apatite (i.e., into a hexagonal calcium phosphate) in the alkaline soils. One thousand nine hundred soil samples were analyzed with the aim of determining the soil phosphorus, potassium, and pH values while using the AI method.

## 2. MATERIAL AND METHODS

In northeastern Slovenia, in four administrative units (i.e., Murska Sobota, Ljutomer, Lendava, and Gornja Radgona), 1,350 samples of grassland soils (i.e., the absolute and relative grasslands) were analyzed for phosphorus, potassium, and the soil  $pH_{KCl}$  content from 2009 to 2014, and 550 samples were analyzed from 2015 to 2019.

The soil samples were analyzed for phosphorus and potassium content according to the AL-method (SIST-TS 1188:2023) and pH value according to the SIST ISO 10390:2022.

Leskovšek (1993) expresses the obtained nutrient contents in soil in mgs of nutrient/100 g of soil and classifies them into the groups marked with the letters A, B, C, D, and E. These are the degrees, or the levels of supply.

For the sake of an analysis, the air-dried soil samples, dehydrated at a temperature of up to 40 °C, crushed, and sieved through a 2-millimeter sieve, were used, whereby the soil samples were prepared in accordance with the SIST ISO 11464 standard.

### 2.1. Determination of Phosphorus and Potassium in the Soil (SIST-TS 1188:2023)

An air-dried soil sample weighing 5.0 g was inserted into a bottle, poured over by 100 ml of working-extraction solution AL, mixed, sealed, and shaken for 2 h ± 5 mins. at a temperature of  $T = 22 \pm 2^\circ C$ . The shaking frequency was such that it prevented settling at the bottom of the bottle. After settling for a few minutes, the filter was extracted so that the following was obtained:

**Table 1 The categories of P2O5 and K2O level in grassland soil according to the AL-method**

**Tablica 1. Kategorije razine P2O5 i K2O u travnjačkome tlu prema metodi AL**

Content in mg/100 g of soil Sadržaj u mg/100 g tla		
Level / Razina	Phosphorus / Fosfor	Potassium / Kalij
<b>A</b> – poor soil / siromašno tlo	< 6	<10
<b>B</b> – medium-supplied soil / srednje opskrbljeno tlo	6–12	10–19
<b>C</b> – well-supplied soil - goal achieved / dobro opskrbljeno tlo - svrha postignuta	13–25	20–30
<b>D</b> – oversupplied soil / preopskrbljeno tlo	26–40	31–40
<b>E</b> – extremely supplied soil / iznimno opskrbljeno tlo	>40	>40

SOURCE: Leskošek (1993)

- **Plant-available phosphorus** was determined spectrophotometrically using the ammonium vanadate method. Phosphorus in the form of phosphate formed a yellow-colored complex with ammonium vanadate, which was determined spectrophotometrically. Absorbance was measured at a wavelength of 406 nm. The phosphorus content is expressed as mg  $P_2O_5/100$  g soil.
- **Plant-available potassium** was determined by atomic absorption spectrometry at a wavelength of 769.9 nm and an air/acetylene oxidizing flame. Potassium was measured directly in the sample extract according to the instrument manufacturer's instructions. Provided that the measured values in the extract were beyond the calibration range, the samples were diluted accordingly. The potassium content is expressed as mg  $K_2O/100$  g soil.

## 2.2. Determination of pH Value in the Soil (According to the SIST ISO 10390:2022 Method)

The pH value is measured as the electrode potential of a combined electrode (calomel/glass). For pedological purposes, the pH value is determined in a 1 mol/l of a potassium-chloride solution (1:5 volume fraction), which displaces hydrogen ions from the soil's intercellular structures. In cases where  $pH < 6$ , the buffer capacity of the soil is also determined by adding a Ca-acetate solution.

Five ml of air-dried soil sample were scooped up using a spoon and transferred into a lidded plastic container. Twenty-five ml of KCl solution were added from a pipette. The container was lidded, mixed well, and placed on a shaker. The suspension was shaken for 60 mins.  $\pm$  10 mins. using a mechanical shaker. After that time, the suspension was let to rest for no more than 3 hours. Subsequent to shaking, the air was prevented from entering during the resting period.

The pH value of the suspension was measured at  $20^\circ C \pm 2^\circ C$ . The suspension was stirred before or during the measurement. The stirring was strong enough to obtain a homogeneous suspension of solid samples without the formation of air bubbles. When the value was stabilized, the pH value was read.

- According to Leskošek (1993), the soil with:
- a pH value higher than 7.2 is alkaline (basic -  $CaCO_3$  predominates)
  - a pH value from 6.8 to 7.2 is neutral (neither acidic nor alkaline)
  - a pH value from 5.6 to 6.8 is moderately acidic
  - a pH value from 4.5 to 5.5 is distinctly acidic
  - a pH value lesser than 4.5 is strongly acidic

## 3. RESULTS AND DISCUSSION

### 3.1. Phosphorus

In the first studied period (i.e., from 2009 to 2014), an average phosphorus content of 10.14 mg  $P_2O_5/100$  g of soil (minimally 0.21 and maximally 172.33 mg  $P_2O_5/100$  g of soil) was achieved in 1,350 analyzed soil samples, while in the second studied period (i.e., from 2015 to 2019) an average phosphorus content of 11.17 mg  $P_2O_5/100$  g of soil (minimally 0.93 and maximally 151.61 mg  $P_2O_5/100$  g of soil) was achieved in 550 analyzed soil samples (Fig. 1).

For both studied periods, it was detected that the soil was at the level B (being a medium-supplied soil). Just under 3 mg  $P_2O_5/100$  g of soil for the first studied period and just under 2 mg  $P_2O_5/100$  g of soil for the second studied period were short of reaching the soil level C (being a well-supplied soil).

One cannot be satisfied with the phosphorus content in the soil in either of the studied periods. However, the results obtained demonstrate that the values achieved were quite close to those obtained by other researchers.

As stated in a research by Leskošek and associates (1998), the Slovenian soils are naturally poorly supplied with phosphorus and somewhat better supplied with potassium. Leskošek and associates also found that the meadows were the least fertilized if compared to the arable land, with approximately 65-75% of soil samples being poorly supplied with phosphorus and potassium.

However, as noted by Stanko Kapun (2000), the region of northeastern Slovenia was detected to have a slightly higher phosphorus supply when compared to the other Slovenian regions. From the results of chemical analyses carried out on 197 samples of grassland soils in the period between

1990 and 2000, 17% of the samples were poorly supplied with phosphorus (A), 36% were moderately supplied (B), 31% were well-supplied (D), 10% were excessively supplied, and 6% were extremely supplied with phosphorus.

Zupan and associates (2018) stated that the phosphates in the soil are strongly bound to the mineral and organic sorptive part thereof, which is why phosphorus can be fertilized for a longer period (as a reserve). The availability of phosphorus bounded to the plants depends on the soil factors, mainly on the soil acidity or the proportion of free carbonates in the soil.

### 3.2. Potassium

Potassium is an important nutrient in plant nutrition. For the studied periods, it was detected that the supply of potassium was at an average higher than the phosphorus content.

For both periods studied, an average potassium content ranged between 15.86 mg of  $K_2O/100$  g and 15.37 mg of  $K_2O/100$  g of soil, respectively. The minimum contents ranged between 1.96 and 3.32 mg of  $K_2O/100$  g of soil, and the maximum contents ranged between 144.84 mg and 77.55 mg of  $K_2O/100$  g of soil (Fig. 2).

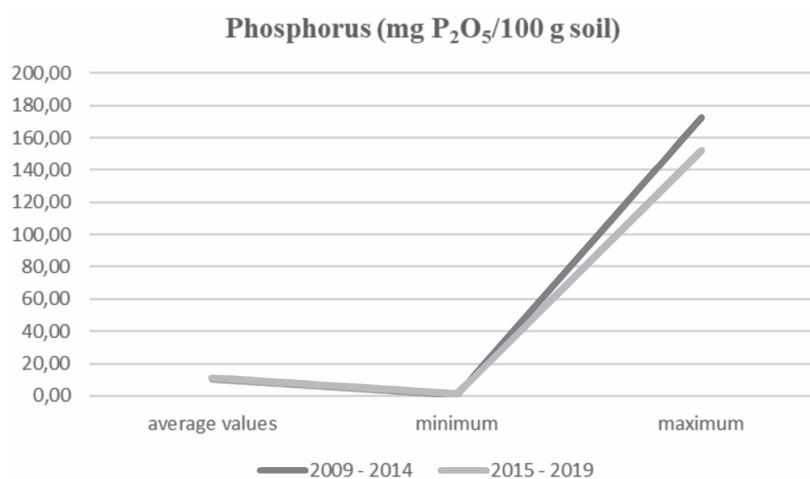


Figure 1 Grassland-soil phosphorus content (mg of  $P_2O_5/100$  g of soil)  
Slika 1. Sadržaj fosfora u travnjačkome tlu (mg  $P_2O_5/100$  g tla).

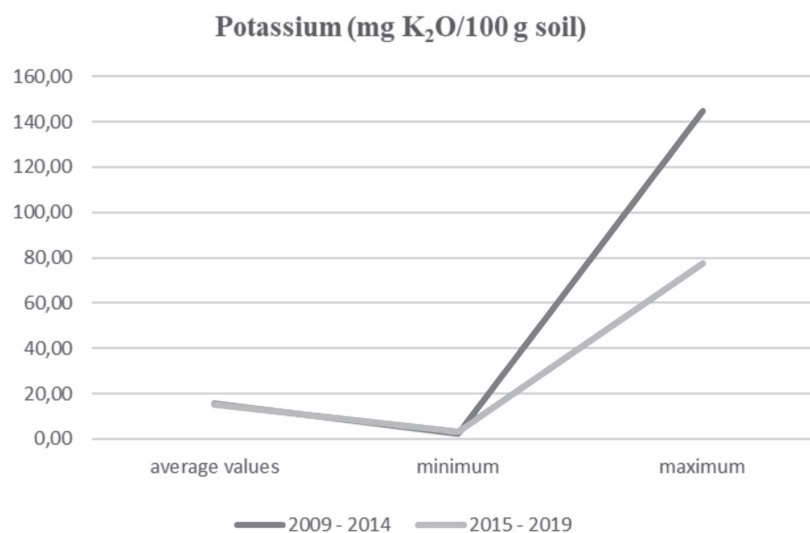


Figure 2 Grassland-soil potassium content (mg of  $K_2O/100$  g of soil).  
Slika 2. Sadržaj kalija u travnjačkome tlu (mg  $K_2O/100$  g tla).

On the basis of results, one may conclude that the meadow soil was moderately supplied (level B) with potassium, amounting to 4 mg/100 g of soil and being too little for both periods studied, 2009-2014 and 2015-2019, respectively.

Potassium helps regulate the plant growth and plays an important role in photosynthesis. A lack of potassium in the soil can have major negative consequences, slowing the growth and even causing the plant to die. A lack of potassium is also manifested as a reduced resistance to drought, cold, and fungal diseases. Too much potassium in the soil, on the other hand, hampers the uptake of calcium and magnesium (Mengel in Kirkby, 1987, quoted by Zupan et al., 2018).

### 3.3. The Soil pH Value

The reaction of the soil solution is determined by the concentration of dissociated hydrogen ions, expressed as a pH value.

It is a negative logarithm of the concentration of H ions ( $\text{pH} = -\log [\text{H}^+]$ ).

A soil reaction affects the physical-chemical processes in the soil and physiological processes in the plants. Soil acidity, or the soil pH value, directly negatively affects the growth and yield of herbage.

A soil reaction affects the physical and chemical processes in the soil and physiological processes in the plants. Soil acidity, or the soil pH value, has a direct negative effect on the growth and yield

of greens. It is also noted that the content of aluminum ions increases in acidic soils, which is harmful to the plants because they hinder the root growth. Also, the availability of phosphorus, calcium, and magnesium decreases in acidic soils (Čop, 2023).

In the area of northeastern Slovenia, the soil is composed of clastic sediments. The most common textural elements are clay, sand, and gravel, which contain little calcium in their chemical composition as the most important carrier of a pH value (Vrščaj et al., 2019).

From the analyzed soil samples, one determines that the average pH value in the first studied period reached an average value of 5.01 (minimally 3.56 and maximally 7.81), while the value amounted to 4.97 (minimally 3.71 and maximally 7.48; Fig. 3) in the second studied period. From the results of chemical analyses, one determines, however, that the studied soils in the region of northeastern Slovenia fall into the category of explicitly acidic soils.

### 3.4. Fertilization

The production potential of the soil is modest, as the pH value should reach the values from 5.2 to 6.8, depending on the proportion of clay in the textural composition (Čop, 2023). As noted by Kapun (2000), in the next five years the grasslands should be fertilized in such a way that the nutrients removed by the crops are replaced by fertilization and that an additional fertilization is applied to build a reserve in order to achieve the C level of phosphorus and potassium supply.

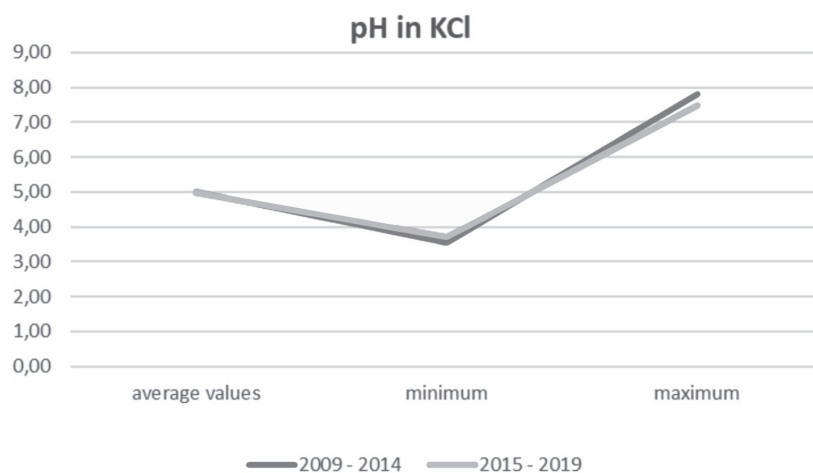


Figure 3 The pH value of grassland soil.  
Slika 3. Vrijednost pH travnjačkoga tla.

The most common mistakes that appear in the field are due to an unbalanced fertilization performed with nitrogen, phosphorus, and potassium. Also underestimated is the calcium content of the soil in the root zone, as liming is still carried out to an insufficient extent. Calcium in the soil changes a botanical composition of the grass sward, so that the consequences of drought in the grassland are expressed later. The input of calcium into the soil improves the structure and microbiological activity of the soil, and thus also the growing conditions thereof (Zavodnik et al., 2017).

Many authors have concluded that the production potential of grasslands in Slovenia is not being sufficiently exploited. The authors such as Gvido Fajdiga (1974), Leskošek (1975), and Jože Korošec (1978) state that the production potential of Slovenian grasslands is at least 100% greater than what is currently harvested from grasslands (quoted in Kapun, 1994). They also state that the productivity of grasslands in Slovenia can be increased by regular fertilization (Leskošek, 1976), introduction of grazing and mowing (Fajdiga, 1976), and by sowing more fertile grass and clover cultivars and their mixtures (Korošec, 1983, quoted in Kapun, 1994).

The intensification of roughage production can also have negative consequences like the reduction of landscape elements, including the loss of natural habitats and a reduction in plant diversity on farms, which leads to a decline in the number and diversity of wild pollinator populations (Foley et al., 2011, quoted in Adamič et al.)

Hans Egnér and associates (quoted in Leskošek, 1998) state that, with regard to phosphorus and potassium, the fertilization counseling based on the AL soil analysis began in 1962.

#### 3.4.1. Instructions for the Calculation of a Fertilization Plan

A fertilization objective is achieved if the C level, or a good supply of the soil with a nutrient, is reached. If the soil is not well-supplied with the nutrients (A and B levels), it is necessary to return to the soil more than the crops take away from it by their annual withdrawal. To increase the soil supply by 1 mg, it is necessary to additionally apply an average of 20 kg of nutrients in addition to the withdrawal. In this way, the soil is enriched with the missing nutrients in five years. The objective is achieved when the C supply level in the soil is reached. When the

supply C level is reached, it is sufficient during the growing season to return to the soil as many nutrients as the plants need (Leskošek, 1993).

On the D and E levels, which indicate an excessive or extreme supply, it is desired to eventually return to the C supply level. It can be achieved by returning only 50% of the withdrawal on the D level and by not fertilizing with the nutrient for which a chemical analysis has determined an extreme soil supply in the next five years on the E level (Leskošek, 1993).

#### 3.4.2. Fertilization with Phosphorus, Potassium, and Calcium

An equation for the calculation of an annual amount of nutrient for grassland fertilization reads as follows:

$$\text{nutrient deficit}/100 \text{ g of soil} \times 20 \text{ kg of pure nutrient} = \text{kg of pure nutrient: 5 years} = \text{stock fertilization} / \text{year} + \text{annual nutrient withdrawal by herbage} = \text{annual amount of nutrient}$$

#### An Equation for the Calculation of an Annual Amount of Lime Fertilizers

If the pH values are too low, soil liming is the basic measure for the fertilization of an agricultural land. It is an essential agrotechnical measure in plant production mainly due to the large yields per hectare, leached basic cations, and the physiologically acidic action of most fertilizers.

According to Leskošek (1993), the pH value of the soil is determined in KCl and in Ca acetate. In the cases in which the pH value is < 6, a buffer capacity of the soil is also determined by adding a Ca-acetate solution.

From the analyzed soil samples, it is established that the average pH (KCl) value in the first period studied reached an average of 5.01, whereas in the second period studied it reached a value of 4.97. It was found that the soils studied in the region of northeastern Slovenia fall into the category of explicitly acidic soils.

The amount of limestone, or of the lime required, can be calculated by taking into account an actual and a desired pH value and molar mass (since the molar mass of CaCO<sub>3</sub> amounts to 100g, it implies that 50 g of CaCO<sub>3</sub> are necessary for each H<sup>+</sup> ion equivalent). When using different calcium raw materials and industrial residues, one must take into account the purity of a calcium raw material used, or the proportion of Ca (Zupan, 2018).

According to Rok Mihelič and Zlata Flisar Novak (2013), these classifications apply:

- light soil - For a pH value  $\leq 4.0$  to 5.0, the following equation applies: lime dose (t CaO/ha) =  $-3 \times \text{pH value} + 16$
- medium-heavy - For a pH value  $\leq 4.0$  to 5.5, the following equation applies: lime dose (t CaO/ha) =  $-3.4 \times \text{pH value} + 19.6$
- heavy soils - For a pH value from  $\leq 4.0$  to 5.6, the following equation applies: lime dose (t CaO/ha) =  $-3.5 \times \text{pH value} + 21$

#### 4. CONCLUSIONS

1. The meadow soils (i.e., the absolute and relative grasslands) were analyzed in the period from 2009 to 2014 and from 2015 to 2019. The meadow soils were sampled in northeastern Slovenia, in the territory of administrative units of Murska Sobota, Lendava, Ljutomer, and Gornja Radgona.
2. For both periods studied, a B level of phosphorus supply (i.e., a medium-supplied soil) was determined. To reach the C supply level (i.e., a well-supplied soil), a little less than 3 mg of  $\text{P}_2\text{O}_5/100$  g of soil were missing in the first period studied and a little less than 2 mg of  $\text{P}_2\text{O}_5/100$  g of soil in the second period studied.
3. The same was true for the meadow-soil potassium content. It pertained to the medium-sufficient soils, or to a B supply level, which signified 4 mg of  $\text{K}_2\text{O}/100$  g of soil, being too modest to reach the lower limit of a good potassium supply, or a C supply level.

An equation for the calculation of an annual amount of nutrient for grassland fertilization reads as follows:

nutrient deficiency/100 g of soil  $\times$  20 kg of pure nutrient = kg of pure nutrient: 5 years = stock fertilization/year + annual nutrient withdrawal by herbage = annual amount of nutrient

4. On average, the soil was distinctly acidic, reaching a  $\text{pH}_{\text{KCl}}$  value of 5.01 and 4.97, respectively. On the light soils, it would be necessary to lime with 1 t/ha of CaO, on the medium-heavy soils with 2.7 t/ha of CaO, and on the heavy soils with 3.3 t/ha of CaO.

5. To improve the meadow soils in the future, one will need to fertilize more intensively with the basic nutrients and, depending on a pH value, focus on an intensive liming of meadow soils. It is important to replace the nutrients removed by the crops with fertilization and to add an additional fertilizer to the supply. In this way, the production capacity of grasslands, which are currently underutilized, will be increased.

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## SAŽETAK

U analizi sadržaja fosfora i kalija te pH vrijednosti tla u uzorku zemlje sušeno-ma na zraku istraživanjem je obuhvaćeno 1.350 uzoraka tla s travnjaka u razdoblju od 2009. do 2014. godine i 550 uzoraka tla s travnjaka u razdoblju od 2015 do 2019. godine. U oba razdoblja ispitivanja sadržaj fosfora kretao se od 10,14 do 11,17 mg  $P_2O_5$ /100g, odnosno dostignuo je vrijednost B razine opskrbljenosti tla fosforom prema tumačenju Mirka Leskoškega (1993). Opskrbljenost tla kalijem u prvome razdoblju ispitivanja bila je u prosjeku 15,86 mg  $K_2O$ / 100g, a u drugome 15,37 mg  $K_2O$ / 100g. U oba razdoblja vrijednost kalija u uzorcima tla pripadala je skupini tala B razine opskrbljenosti tla kalijem, dok je pH vrijednost u oba razdoblja ispitivanja bila izričito kisele reakcije, prosječno pH 5. Na osnovi rezultata ispitivanja pripremljene su opće preporuke za gnojidbu i kalcifikaciju travnjaka.

Ključne riječi: kemijska analiza, travnjak, fosfor, kalij, pH vrijednost, preporuke za gnojidbu