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ANALYSIS OF A SHEEP PASTURE ECOSYSTEM IN THE PIENINY MOUNTAINS (THE CARPATHIANS)

VI. THE EFFECT OF PENNING-UP SHEEP ON SOME CHEMICAL PROPERTIES OF SOIL*

ABSTRACT: Intensive penning-up sheep considerably modifies chemical properties of soil. Physical degradation and an increase in the content of mineral N and available K to a toxic level account for the destruction of turf. High concentrations of N and K are maintained for several weeks after penning-up sheep and they decrease only with an increase in plant production. Insignificant vertical and horizontal movements of soil elements were observed. The possibilities of movements were different for different elements. The rhythm of biological changes after penning-up sheep was closely related to the dynamics of chemical modifications in soil.

1. INTRODUCTION

The mountain pastures of the Małe Pieniny mountains are characterized by a low productivity, despite favourable soil and climatic conditions (S w e d e r s k i and S z a f r a n 1932, K i e ł p i ń s k i, K a r k o s z k a and W i ś n i e w s k a 1958). This is a result of extensive management consisting of grazing sheep without any additional treatments. The pastures are only fertilized due to the continuous moving of the sheep-folds, where sheep stay at night and during milking.

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Undoubtedly, the presently used methods of penning-up sheep in the area under study are considerably different from those being recommended (Kiełpiński, Karkoszka and Wiśniewska 1958), and penning-up sheep as such is not a sufficient way of fertilizing as it involves only a small part of the grazed area. Therefore, the productivity of these pastures depends only on the natural fertility of soil and it is limited by the amount of mineral nutrients released in biochemical processes. The unreasonable penning-up of sheep, i.e., too small an area per sheep in a fold (below 1 m^2 per day), and an irregular distribution of sheep manure result in the overfertilizing of small areas in a short time and subsequently, in an almost complete destruction of turf.

The purpose of this study was to analyse the effect of penning-up sheep on the chemical properties of the top layers of soil, and to relate the chemical changes in the soil to biological changes taking into consideration the zoological and microbiological studies carried out in these pastures (Andrzejewska 1974, Breymeyer 1974, Czerwiński et al. 1974, Czerwiński, Jakubczyk and Nowak 1974, Delchev and Kajak 1974, Jakubczyk 1974, Olechowicz 1974, Pętal 1974, Wasilewska 1974, Żyromska-Rudzka 1974, Nowak – in press).

The studies were carried out on brown leached soils developed from the carbonate flysch of the Upper Cretaceous period, which are characteristic of this region (Czerwiński and Tatur 1974).

2. METHODS

The samples of soil for chemical analyses were taken at different depths of the surface layer a definite time after the penning-up of sheep. The dates and depth of sampling are given in the tables and figures. Total N was analysed by Kiejdahl's method, mineral N (N–NH_4, N–NO_3 and N–NO_2) was extracted with 5% K_2SO_4 and colorimetrically estimated using the indophenolic method for N–NH_4, the phenyldisulphonic method for N–NO_3 and Griess' method for N–NO_2. The content of exchangeable cations (Ca, Mg and K) was found by Pallmann's method, K_2O and available P_2O_5 by Egner-Riehm's method, organic C by Tiurin's method, pH in H_2O and in 1 n KCl by the potentiometric method using a glass electrode; the forms of nitrogen and pH were determined immediately after sampling (excluding pH in Table II).

The results are presented in the tables as an arithmetic mean of six samples of soil taken and analysed at the same time. Also the total content of mineral components in sheep manure was determined once.

3. RESULTS

Penning-up sheep in the mountain pastures near the village Jaworki was much more intensive during the study period than was recommended. The density exceeded one sheep per m^2 per day. It was calculated taking into account the production of manure and its chemical composition (Kiełpiński, Karkoszka and Wiśniews k a 1958), that in this case at least 139 kg of N, 37 kg of P_2O_5 and 112 kg of K_2O per ha passed into the soil.

After the penning-up of sheep their manure was not spread on the pastures, so its distribution was not uniform, and areas covered with a thick layer of manure adjoined areas almost completely without manure. This manure was rapidly decomposed. The rate of both the decomposition processes and the penetration of the products of decomposition into the soil primarily depends on atmospheric conditions (F l o a t e 1970a, 1970b). Urine and the products of manure decomposition chemically destroy the vegetation over a considerable part of the sheep-fold areas. In addition, the turf can also be mechanically destroyed by sheep, when their density is high. A measure of the destruction of turf is the ratio of the area deprived of vegetation to that covered with vegetation (Tab. I). The vegetation was restored in almost the whole area (90%) at favourable weather conditions for about 100 days after penning-up sheep. The areas covered by comparatively larger amounts of manure were deprived of vegetation for the longest period.

Tab. I. Proportion of turf area destroyed

Days after penning-up sheep	Per cent of turf area destroyed
3	75
12	50
30	25
130	5

When the turf is destroyed, the input of fresh organic matter in the form of roots and above-ground parts into the soil is stopped. Sheep manure immediately after deposition is also a comparatively poor source of organic compounds. The content of organic compounds in the soil covered with a layer of manure can be lowered (Tab. II) at that time because of a higher rate of mineralization than humification processes, as it was found in a sheep-fold of August, 1969. The most intensive mineralization, followed by the input of nitrogen into the soil, during the first period after penning-up sheep is indicated by C:N ratio ranging from 8.3 to 9.3. Due to both the gradual penetration of sheep manure into the soil (soil fauna, precipitations) and the restoration of turf, the content of organic matter in the soil continuously increased. The increase in the content of soil organic matter reached the maximum about a year after the penning-up of sheep. A simultaneous increase in C:N ratio (Tab. II) indicates that the content of labile non-humic substances in the soil organic matter increased.

Immediately after penning-up sheep the content of ammonia nitrogen and available potassium rapidly increased in the top soil layer covered with manure (Figs. 1, 2). The rapid changes in the content of these two compounds during the first phase resulted from the percolation of sheep urine into the soil. This urine contained 1.5% of potassium in the form of dissociated salts, and 1.8% of nitrogen in the form of urea, hippuric acid and uric acid (G ó r s k i 1957). The nitrogen was converted to ammonia during several days. Although low temperatures inhibited the processes of urea hydrolysis (F i s c h e r and

Tab. II. Influence of sheep on the surface layers (0–10 cm) of soil

A – area covered by sheep manure, *B* – area not covered by sheep manure

Date of penning-up sheep	Date of sampling	Area	pH		mg/100 g of soil		C (%)	Organic matter (%)	N (%)	C:N
			in H_2O	in KCl	K_2O	P_2O_5				
May 1969	13 May 1970		5.75	4.93	53.0	0.8	2.95	5.08	0.317	9.3
June 1969	8 July 1970		6.35	5.55	29.0	0.8	2.03	3.50	0.226	9.0
	16 Sept. 1970		6.23	5.38	25.0	0.2	2.34	4.03	0.230	10.2
Aug. 1969	13 May 1970	*A*	6.28	5.16	25.9	0.8	2.05	3.53	0.234	8.8
		B	6.82	5.50	6.5	0.5	2.32	3.99	0.250	9.3
	8 July 1970	*A*	6.10	5.22	25.2	0.9	2.20	3.79	0.240	9.2
		B	6.67	5.66	5.6	0.4	2.43	4.19	0.252	9.6
	16 Sept. 1970	*A*	6.10	5.16	14.4	1.2	2.25	3.88	0.215	10.4
		B	6.67	5.70	5.6	0.8	2.64	4.55	0.263	10.0
	25 Aug. 1971	*A*	5.95	5.12	14.1	0.8	2.16	3.72	0.169	12.8
		B	6.67	5.87	5.7	0.5	2.64	4.55	0.222	11,9
May 1970	3 June 1970		6.23	5.55	38.0	1.1	2.48	4.27	0.298	8.3
	8 July 1970		6.30	5.55	30.0	0.4	2.55	4.40	0.286	8.9
	16 Sept. 1970		6.10	5.35	26.0	0.5	2.60	4.48	0.280	9.3

P a r k s 1958) the content of N–NH_4 at a depth of 0–2 cm considerably exceeded 240 ppm within a day after penning-up sheep (Fig. 1). During the first days after manuring a vertical movement of nitrogen was observed. The nitrogen contained in urine can readily be transported into the soil, but after being converted to ammonia nitrogen its possibility of movement is considerably limited (B r o a d b e n t 1958). During the next stage, some weeks after penning-up sheep, the soil is continuously enriched with nutrients released from the rapidly decomposing sheep manure (O l e c h o w i c z 1974). Heavy precipitation and high temperatures (Tab. III) speed up these processes (F l o a t e 1970a, 1970b, J a k u b c z y k 1974).

The faeces analysed in September contained about 2.0% of total N and 1.5% of K_2O. The maximum concentration of N–NH_4 at a depth of 0–5 cm was observed after 12 days, and at a depth of 5–10 cm after 30 days from the moment of penning-up sheep (Fig. 1).

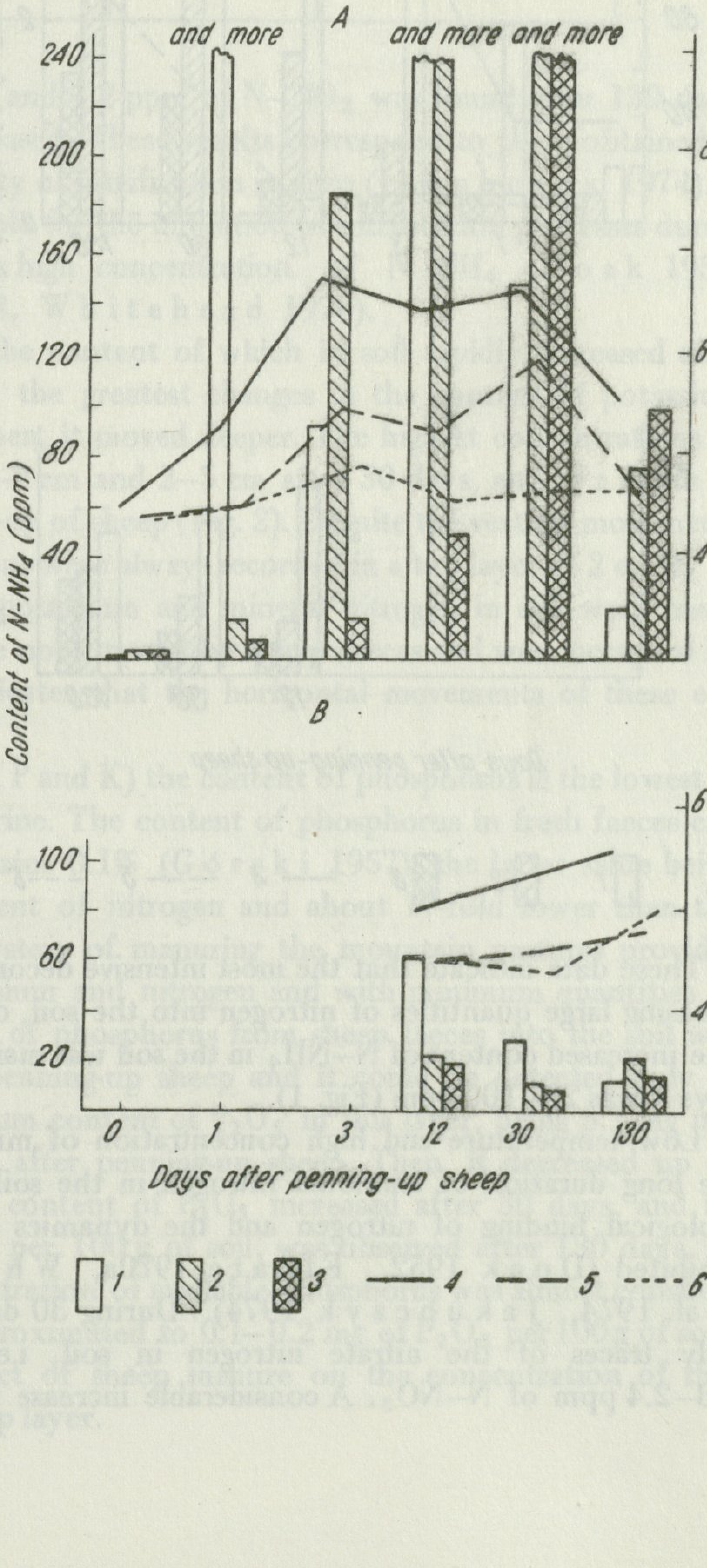

Fig. 1. Influence of penning-up sheep on the content of N–NH_4 in soil and on changes in the pH

A – area covered by sheep manure, *B* – area not covered by sheep manure, *1* – content of N–NH_4 in 0–2 cm soil layer, *2* – content of N–NH_4 in 2–5 cm soil layer, *3* – content of N–NH_4 in 5–10 cm soil layer, *4* – pH in 0–2 cm soil layer, *5* – pH in 2–5 cm soil layer, *6* – pH in 5–10 cm soil layer

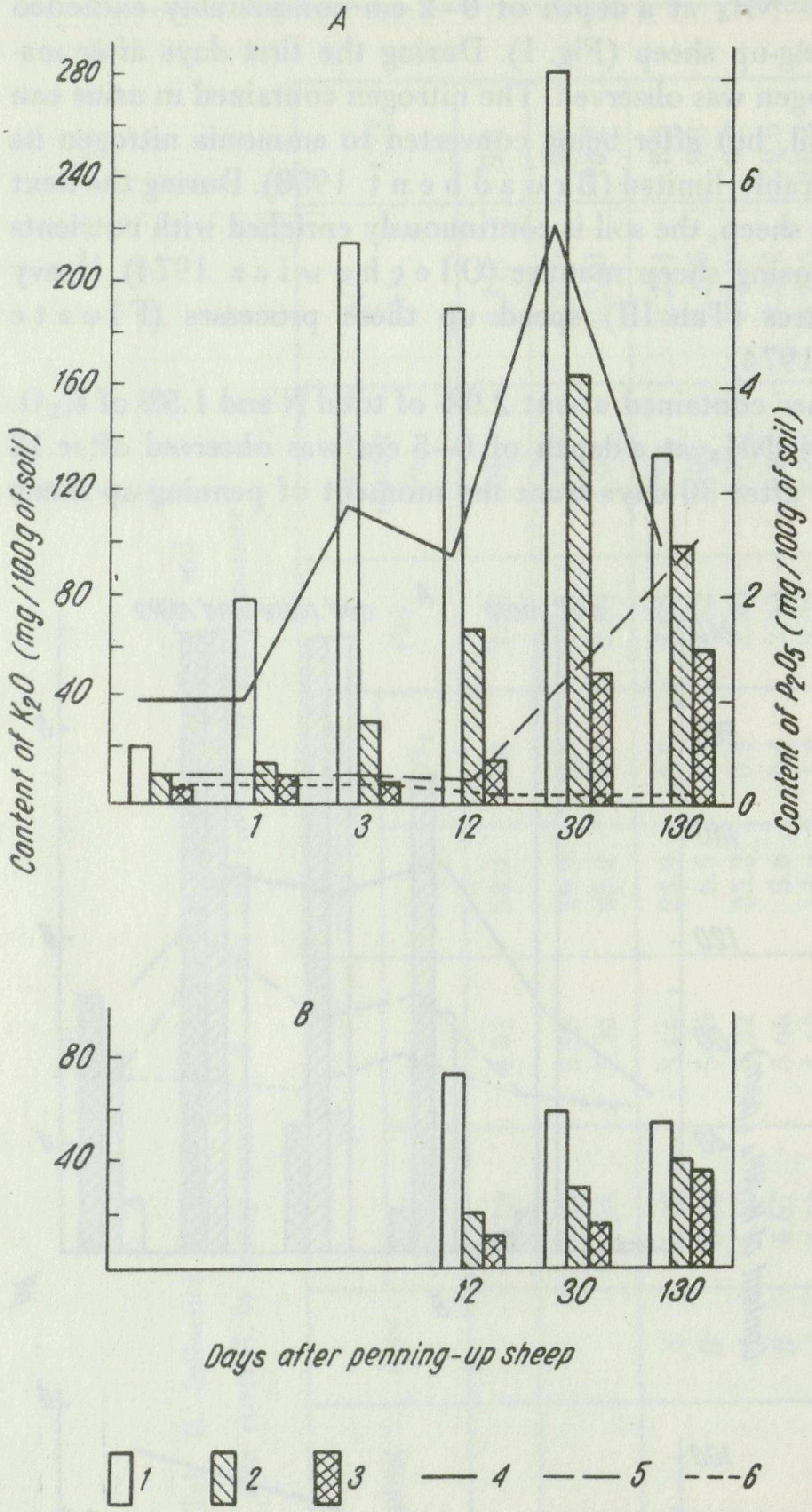

Fig. 2. Contents of K_2O and P_2O_5 in soil

A – area covered by sheep manure, *B* – area not covered by sheep manure, *1* – content of K_2O in 0–2 cm soil layer, *2* – content of K_2O in 2–5 cm soil layer, *3* – content of K_2O in 5–10 cm soil layer, *4* – content of P_2O_5 in 0–2 cm soil layer, *5* – content of P_2O_5 in 2–5 cm soil layer, *6* – content of P_2O_5 in 5–10 cm soil layer

These data indicate that the most intensive decomposition of manure, which results in releasing large quantities of nitrogen into the soil, occurs within 30 days after manuring. The increased content of $N\text{–}NH_4$ in the soil was maintained for a long time and after 130 days it was 20–100 ppm (Fig. 1).

Low temperature and high concentration of mineral nitrogen largely contributed to the long duration of ammonia nitrogen in the soil. For these reasons both the rate of biological binding of nitrogen and the dynamics of nitrogen conversions in soil were inhibited (Doak 1952, Floate 1970a, Whitehead 1970, Czerwiński et al. 1974, Jakubczyk 1974). During 30 days after penning-up sheep there were only traces of the nitrate nitrogen in soil, i.e., 0.33–0.72 ppm of $N\text{–}NO_2$ and 1.8–2.4 ppm of $N\text{–}NO_3$. A considerable increase in the content of these forms of ni-

Tab. III. Precipitation and temperature of soil

Days after penning-up sheep	Precipitation (mm)		Average temperature (°C) of soil at 5 cm depth
	sum for the period	average per day	
0–1	0	0	10.5
1–3	0.3	0.1	10.6
3–12	52.0	5.8	12.6
12–30	60.0	3.3	13.5
30–130	480.0	4.8	14.7

trogen up to 34.0 ppm of $N-NO_3$ and 1.2 ppm of $N-NO_2$ was found after 130 days, when the content of $N-NH_4$ decreased. These results correspond to these obtained in microbiological studies on the activity of nitrification in vitro (J a k u b c z y k 1974). It seems that the main factor responsible for the inhibition of nitrification processes during the first weeks after manuring is a high concentration of $N-NH_4$ (D o a k 1952, N o m m i k and N i l s s o n 1963, W h i t e h e a d 1970).

Potassium is the other element the content of which in soil rapidly increased after penning-up sheep (Fig. 2). Initially, the greatest changes in the content of potassium occurred in the top 2 cm of soil. Then, it moved deeper. The highest concentrations of K_2O were observed at depths of 0–2 cm and 2–5 cm after 30 days, and at a depth of 5–10 cm 130 days after the penning-up of sheep (Fig. 2). Despite the vertical movements of potassium, its highest concentrations were always recorded in a top layer of 2 cm.

The concentrations of available potassium and mineral nitrogen in soil were many times lower in the places which were not covered by sheep faeces and were occupied by the vegetation (Figs. 1, 2). This indicates that the horizontal movements of these elements were very limited.

From the three basic elements (N, P and K) the content of phosphorus is the lowest in sheep faeces, and in particular in urine. The content of phosphorus in fresh faeces calculated as P_2O_5 was 0.2%, and in urine 0.1% (G ó r s k i 1957), the latter value being about 15-fold lower than the content of nitrogen and about 17-fold lower than the content of potassium. Thus, this system of manuring the mountain pastures provides them with large quantities of potassium and nitrogen and with minimum quantities of phosphorus (Fig. 2). The movement of phosphorus from sheep faeces into the soil was very slow in the first period after penning-up sheep and it could be detected only in a surface layer of 2 cm. The maximum content of P_2O_5 in this layer, being 5.1 mg per 100 g of soil, was recorded 30 days after penning-up sheep. Then, it decreased up to 2.5 mg. At a depth of 2–5 cm the content of P_2O_5 increased after 30 days, and its highest concentration, up to 2.4 mg per 100 g of soil, was observed after 130 days. In a deeper layer (5–10 cm) the concentration of available phosphorus was almost constant throughout the study period and approximated to 0.1–0.2 mg of P_2O_5 per 100 g of soil. These results indicate that the effect of sheep manure on the concentration of this element in the soil is limited to the top layer.

Ammonia released in microbiological processes renders the soil more alkaline (Fig. 1). The pH of the top 2 cm of the soil was changed from very acid to neutral within three days. A neutral pH was maintained throughout the period of high ammonia concentra-

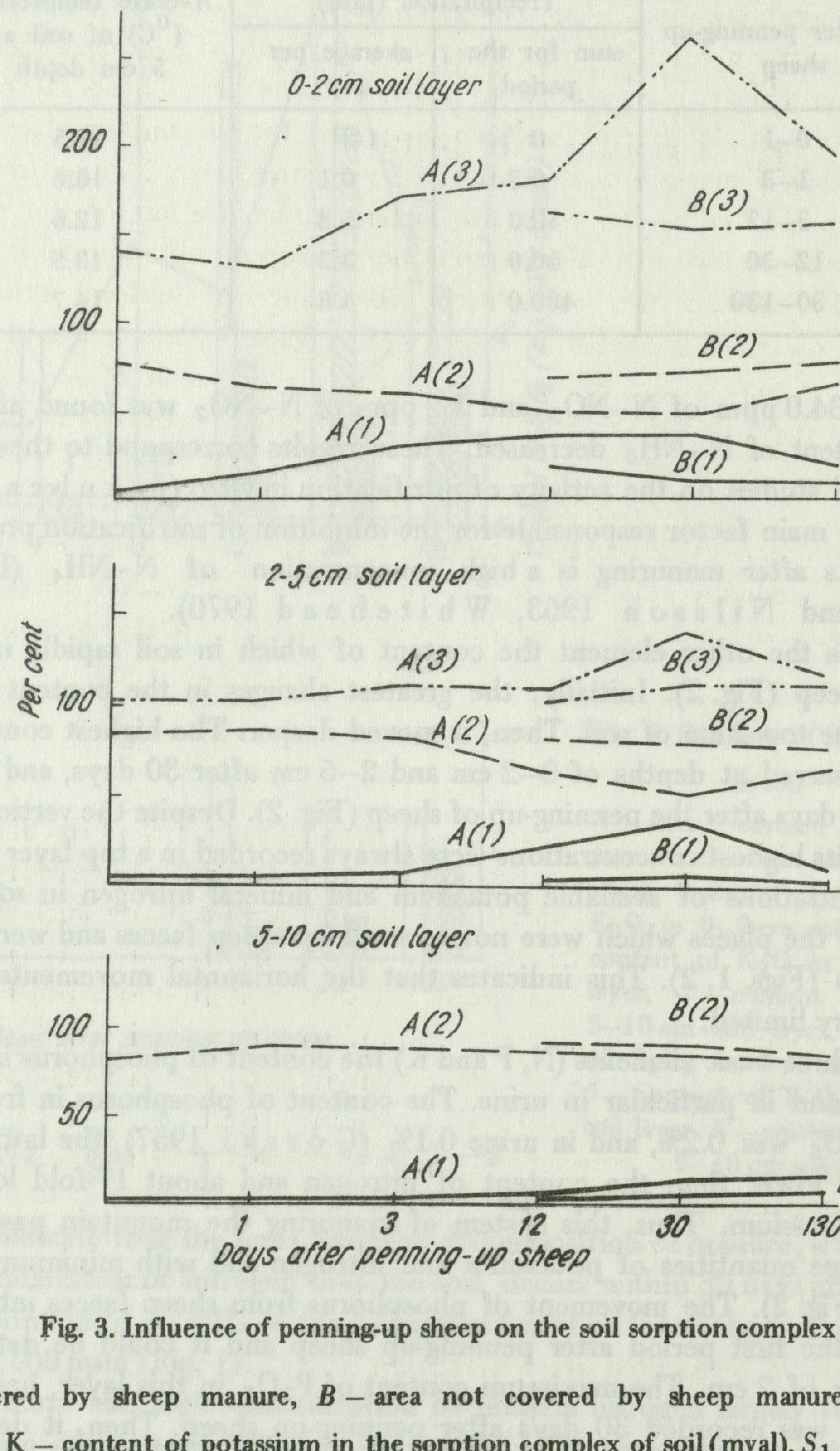

Fig. 3. Influence of penning-up sheep on the soil sorption complex

A – area covered by sheep manure, B – area not covered by sheep manure, (1) – per cent $K = \frac{K}{S_1} \times 100$; K – content of potassium in the sorption complex of soil (mval), S_1 – sum of metallic cations in the sorption complex of soil (mval); (2) – per cent $Ca = \frac{Ca}{S_1} \times 100$; Ca – content of calcium in the soil sorption complex (mval), S_1 – sum of metallic cations in the soil sorption complex (mval); (3) – per cent $\Delta S = \frac{S_1 \text{ 0–2 cm or } S_1 \text{ 2–5 cm}}{S_1 \text{ 5–10 cm}} \times 100$; S_1 – content of metallic cations in the soil sorption complex at depths of 0–2, 2–5 and 5–10 cm (mval)

tion. But the ammonia leached by water reacts with other ions, being gradually converted to neutral salts. Hence, the effect of the high concentration of N–NH_4 on the soil reaction was more and more reduced with increasing depth (Fig. 1).

Sheep manure mechanically pushed into the surface layer of the soil and organic compounds soluble in water are additional sorbents temporarily increasing the total number of exchangeable cations. A considerable increase in the S_1 value (Ca + Mg + K + Na in the soil sorption complex) was observed at a depth of 0–2 cm (Fig. 3) as compared to the areas lightly manured or to a deeper layer from 5 to 10 cm, which is characterized by a high stability of sorption properties for all sampled places and dates (Fig. 3). The maximum increase in the value of S_1 occurred after 30 days from penning-up sheep. This period coincided with the highest concentration of the products of manure decomposition and with the percolation of organic compounds into the soil, which is proved by yellow-brown soil extracts. The changes of this kind, although not so pronounced, also occurred at a depth of 2–5 cm (Fig. 3). Also the changes in the proportions of metallic cations in the soil sorption complex are a result of penning-up sheep. A considerable increase in the percentage contribution of K cations was observed. The highest proportion of K cations in the sorption complex was at a depth of 0–2 cm, while in deeper layers it was considerably lower.

As time went on and the effect of decomposing sheep manure decreased, the sorption properties of soil gradually returned to the original state (Figs. 2, 3). A high concentration of available K in soil was maintained for a longer time than that of mineral N.

4. DISCUSSION

The present results indicate that penning-up sheep as a method of the natural fertilizing of mountain pastures is not effective because it is not carried out in a proper way. Because the number of sheep kept in a fold is higher than recommended (Kiełpiński, Karkoszka and Wiśniewska 1958), the areas used as sheep-folds are overfertilized, the turf being both chemically and mechanically destroyed by the sheep. The deleterious results of the improper penning-up of sheep are intensified by the fact that afterwards the area is left to its fate, such a simple treatment as spreading the manure over the whole area not being carried out. In the overfertilized areas the chemical resources which determine the productivity of an ecosystem are frozen. In addition, this system of natural manuring results in the losses of elements introduced into the soil with the manure. As ammonia is volatile into the atmosphere, considerable losses of nitrogen take place. In the areas without vegetation a considerable amount of elements can be leached.

The vegetation of destructed areas is restored when the concentration of N–NH_4 is lowered up to 70 ppm and the concentration of potassium up to 2 mval per 100 g of soil. The areas used as sheep-folds are generally occupied by nitrogen fixing plants, which are not consumed by animals (thistles, alpine sorrel and others). As it has been found in a separate experiment (Kiełpiński, Karkoszka and Wiśniewska 1958, Czerwiński et al. 1974) and from the literature data, reasonable penning-up sheep minimally disturbing the turf of the pasture result in several times higher yields of green parts. The current system of manuring the pastures is relatively incomplete as it provides soil mainly with nitrogen and potassium. A great excees of these two elements is accompanied by a significant phosphorous deficiency in soil.

Immediately after manuring a great concentration of $N-NH_3$ and exchangeable K is observed in the surface layer of soil due to the leaching of sheep manure and to its rapid mineralization through microbiological processes (J a k u b c z y k 1974). In overmanured areas high concentrations of these elements have a toxic effect on the soil flora and fauna. The vegetation is destroyed and disturbances in the balance of development of particular soil fauna groups are observed. In particular, this is the case of the species inhabiting the surface soil layer (A n d r z e j e w s k a 1974, B r e y m e y e r 1974, C z e r w i ń s k i, J a k u b c z y k and N o w a k 1974, D e l c h e v and K a j a k 1974, J a k u b c z y k 1974, O l e c h o w i c z 1974, P ę t a l 1974, W a s i l e w s k a 1974, Ż y r o m s k a - R u d z k a 1974, N o w a k – in press).

High concentrations of $N-NH_3$ and exchangeable K are maintained for several weeks after the penning-up of sheep, then they gradually decrease due to diffusion, leaching, transformation into the gas phase and, primarily, due to biological binding. This is followed by an increase in plant production with grasses as the predominating species, and by the development of microorganisms utilizing mineral nitrogen (C z e r w i ń s k i et al. 1974, J a k u b c z y k 1974). After using the available nutrients, fauna and flora return to the original biological balance.

Besides the injurious effect of the inappropriate penning-up of sheep on the turf, keeping sheep for a longer time in the area covered by wet manure affects their health, and a great number of sheep suffer from agnail.

5. SUMMARY

The study has been carried out in the extensively exploited pastures in the Małe Pieniny mountains. The only form of fertilizing this area is the penning-up of sheep. This treatment results in significant changes of the chemical properties of the soil. Immediately after manuring a great concentration of mineral nitrogen and available potassium is observed in the surface layer of soil (Figs. 1–3). In the overmanured areas the concentration of these elements is toxic for soil flora and fauna. The vegetation is destroyed (Tab. I); there are also disturbances in the developmental balance of different fauna groups, particularly those living in the surface soil layer. High concentrations of nitrogen and potassium in soil are maintained for several weeks after penning-up sheep, and they decrease only with increasing plant production.

Differences in the dynamics of movement of different elements through soil were observed. Both horizontal and vertical movements of elements in soil are rather restricted and can be measured in centimeters. After using the available nutrients, the state of original balance is restored in the biocenosis.

The results obtained confirm the opinion that the rhythm of biological changes after manuring is closely related to the dynamics of chemical changes in soil.

6. POLISH SUMMARY (STRESZCZENIE)

Badania prowadzono na obszarach ekstensywnie eksploatowanych pastwisk owczych w Małych Pieninach. Intensywne koszarowanie jest jedyną stosowaną tam akutalnie formą nawożenia. Zabieg ten powoduje istotne zmiany w chemizmie gleby. Bezpośrednio po nawożeniu następuje olbrzymia koncentracja azotu mineralnego i potasu wymiennego w powierzchniowej warstwie gleby (fig. 1–3).

W miejscach przenawożonych stężenia wymienionych pierwiastków oddziałują toksycznie na florę i faunę gleby. Roślinność zostaje zniszczona (tab. I); obserwujemy również zakłócenia równowagi w rozwoju poszczególnych grup fauny, a zwłaszcza gatunków egzystujących w przypowierzchniowej warstwie gleby. Wysokie stężenia azotu i potasu utrzymuja się w glebie przez kilka tygodni od momentu koszarowania i zmniejszają się dopiero wraz ze wzrostem produkcji roślinnej.

Obserwowano odmienną dynamikę rozchodzenia się w glebie różnych pierwiastków. Migracja pierwiastków, zarówno w kierunku poziomym jak i pionowym, jest ogólnie dość ograniczona i może być rejestrowana w skali centymetrowej. Po wykorzystaniu przyswajalnych biogenów biocenoza powraca do stanu równowagi sprzed zabiegu koszarowania.

Przeprowadzone badania potwierdziły pogląd, że rytm zmian biologicznych po nawożeniu pozostaje w ścisłej zależności z dynamiką przemian chemicznych w glebie.

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