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SEASONAL NITROGEN MINERALISATION DYNAMICS IN THE SOIL OF A *GENISTO-CALLUNETUM ILLYRICUM* Ht. 31 ASSOCIATION ON PERMANENT PLOT 84 – THE PLITVICE LAKES NATIONAL PARK (CROATIA)

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Seasonal nitrogen mineralisation dynamics was investigated in the *Genisto-Callunetum illyricum* Ht. 31. association (permanent plot No. 84). The absence of anthropozoogenic influences on the plot in the period of 35 years caused the accumulation of a great amount of organic material and changed the appearance of the vegetation. The investigation into the seasonal nitrogen mineralisation dynamics in the course of 1989 and 1990 was made by incubation method at the site and in laboratory conditions. Great nitrogen mineralisation variability from term to term in the course of different years of investigation was established. That variability was caused by a higher number of external factors as well as by the variability of the samples. A high nitrification degree (up to 90%), which is usually rare in the heath type vegetation, was most probably caused by a large quantity of organic matter that had accumulated on the plot surface. Nitrogen leaching in humid climate conditions is characteristic of the Plitvice Lakes area, renewed grazing and occasional fires will reduce the mineral nitrogen amount and nitrate percentage to the level that is favourable for heaths.

Introduction

A Hundred Permanent Plots of the Republic of Croatia project includes a large number of significant plant communities in Croatia. All permanent plots within that project have the size of 1 ha and were set up with the aim of carrying out permanent multidisciplinary investigations (Ilijanić and Meštrov 1975). On the territory of the Plitvice Lakes National Park four permanent plots were set up in 1988 and were marked by the numbers 81, 82, 83 i 84 (Šegulja and Krga 1989).

On permanent plot number 84 being protected against anthropogenic influences for more than 35 years *Calluna vulgaris* became dominant. The heath vegetation stands are generally considered to be poor in nutrients (Lache 1976), and to have acid soils without nitrification (Kriebitzsch 1978). That prompted us to investigate net nitrogen mineralisation in the soil during two vegetation seasons (1989 and 1990). In terrestrial ecosystems mineral nitrogen i.e. nitrates and ammonium are the only ecologically relevant forms of nitrogen (Runge 1965). Nitrogen mineralisation is quantitatively the most significant process and the nitrogen supply in the ecosystem depends on it (Ellenberg 1964, 1977). The mineralisation processes in the soil depend mostly on humidity and temperature of the soil (Ellenberg 1964, 1977, Runge 1983, Zöttl 1958). Thus, the seasonal changes of these two factors are likely to influence seasonal changes in the mineralisation intensity as well. Data on the seasonal nitrogen mineralisation dynamics and nitrification are rather scarce in Croatia at the moment (Hršak 1987, 1993, Hršak and Ilijanić 1987). Hence, this paper brings some new data on the issue.

Object and area of research

Permanent plot number 84 is located in the area of Brezovačko Polje in the south-western part of the Plitvice Lakes National Park (Fig. 1). Brezovačko polje is a plane at 760–780 meters above sea level covered with various types of grassland vegetation. The vegetation on the permanent plot 84 belonged to the *Genisto-Callunetum illyricum* Ht. 31 association (*Nardo-Callunetea* Preising 49 class). At the time the plot was set up, in 1988, the state of vegetation ("0") was established. The floristic composition in shown in Table 1. For 35 years or more there had been no grazing, cutting and burning at a large number of grasslands within the National Park including the site of permanent plot No. 84. A layer of partly decomposed plant residues of the vegetation from earlier years, which was about 10 cm thick in places, accumulated at the plot and heather bushes grew up to 40–70 cm covering up to 80% of the surface (Šegulja and Krga 1989). However, in 1989 when the investigations of nitrogen mineralisation actually started, anthropozoogenic influences were renewed in an unplanned manner in the Brezovačko polje area. A herd of about 700 sheep came from western Bosnia to this area for grazing and remained in the area, while at the end of winter and in early spring 1990 the surface of the plot was struck by fire on two occasions. The vegetation was burnt down as was the layer of plant residues. Thus, the surface of the plot was almost totally bare at the beginning of the vegetation season 1990.

Materials and Methods

The usual methods of the Zürich-Montpellier phytocoenological school (Braun-Blanquet 1964) were used in the vegetation investigations. In the period of three years (1988, 1989, and 1990) 15 phytocoenological records

Table 1. Ass. *GENISTO-CALLUNETUM ILLYRICUM* Ht. 31 (permanent plot No. 84)

Rec. Nr.	1	6	11
Position on plot and recording year	A88	A89	A90
Surface in m	80	80	50
Species Nr.	44	29	29
CHAR. ASS. *(Genisto-Callunetum illyricum)*			
Calluna vulgaris (L.) Hull	4	3	2
CHAR. ALL., ORD., CLASS. (Calluno-Festucion, Nardetalia, Nardo-Calluneta)			
Potentilla erecta (L.) Räuschel	2	3	3
Carex pilulifera L.	1	2	1
Molinia arundinacea Schrank	2	1	2
Chamaespartium sagittale (L.) Gibbs	3	3	2
Viola canina L.	1	1	1
Nardus stricta L.	+	1	1
Luzula campestris (L.) DC.	+	1	1
Lembotropis nigricans (L.) Griseb.	1	.	.
Polygala vulgaris L.	.	1	.
Veronica officinalis L.	+	.	.
Danthonia decumbens (L.) Bernh.	.	.	+
Holcus mollis L.	.	.	+
COMP.			
Euphorbia verrucosa L.	3	2	2
Festuca rubra L.	2	1	1
Festuca pseudovina Hackel	2	.	+
Knautia purpurea (Vill.) Borb.	1	1	1
Rumex acetosa L.	1	+	1
Galium verum L.	1	1	1
Brachypodium pinnatum (L.) PB.	+	.	1
Anthoxanthum odoratum L.	1	1	1
Briza media L.	1	1	1
Hypericum perforatum L.	1	.	1
Stellaria graminea L.	1	1	.
Thymus sp.	1	+	+
Carlina acaulis ssp. *simplex* Nyman	1	+	1
Filipendula vulgaris Moench.	+	+	+
Thesium divaricatum Jan.	1	1	+
Agrostis canina L.	1	.	.
Achillea millefolium L.	1	.	+
Polygala amara L.	1	.	.
Lathyrus tuberosus L.	.	+	.
Cruciata glabra (L.) Ehrend.	.	1	.
Plantago lanceolata L.	+	+	+
Leucanthemum vulgare Lam.	.	+	+
Rhinanthus glacialis Personn	1	.	.
Luzula luzuloides (Lam) Dandy & Wilm.	.	+	.
Cerastium holosteoides Fries.	+	.	.
Centaurea jacea L.	+	.	.
Galium mollugo Mill.	+	.	.
Rumex crispus L.	+	.	.
Leontodon hispidus L.	.	1	.
Linum catharticum L.	.	+	.
Avenochloa pubescens (Huds.) Gollb.	+	+	.
Salvia pratensis L.	+	.	.
Gentiana utriculosa L.	1	.	.
Cirsium acaule Scop.	+	.	.
Plantago media L.	+	.	.
Trifolium montanum L.	+	.	.
Viola hirta L.	+	.	.
Trifolium pratense L.	+	.	.
Viola tricolor L.	+	1	.
Carex verna Chaix	+	.	.
Agrostis tenuis Sibth.	.	.	3
Aristolochia pallida Willd.	.	.	+

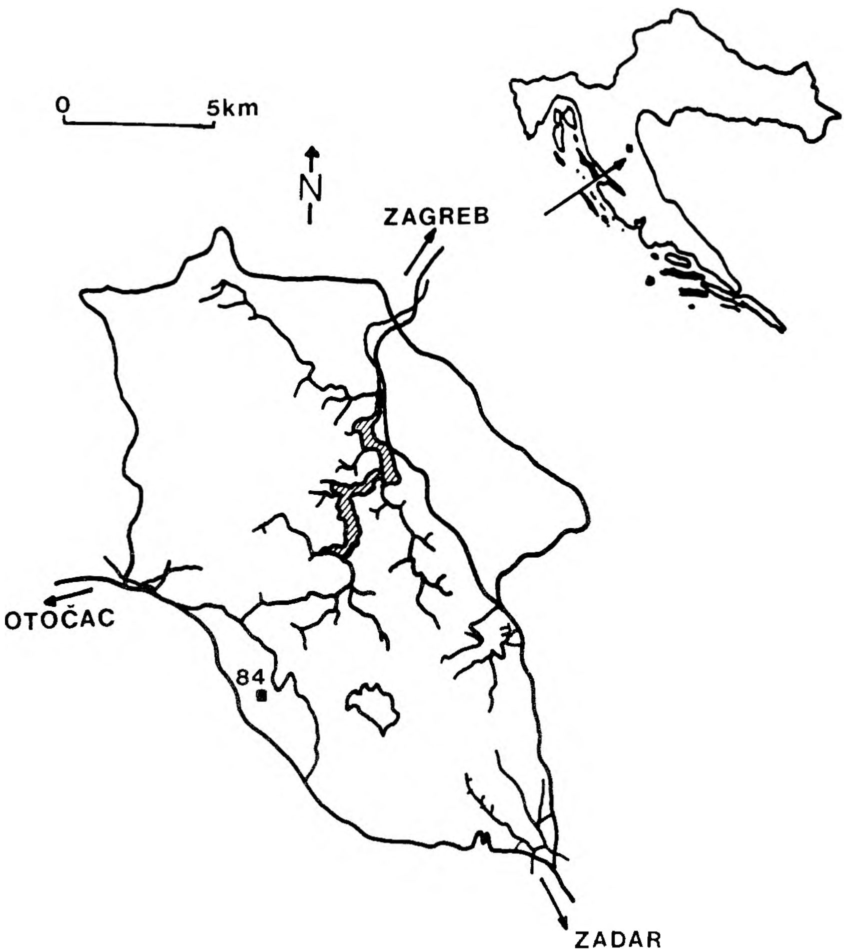

Fig. 1. Position of permanent plot 84 in the Plitvice Lakes National Park.

were made (five records per year) at the same spots within the plot (14 diagonal steps from the boundary poles towards the centre of the plot and in the very centre of the plot).

Soil samples were collected for analysis in time periods of 3 weeks during the vegetation seasons of 1989 and 1990. An average soil sample from the depth of 0–15 cm was taken. Due to great humidity of some samples, the soil did not render itself to sieving, so roots and stones were removed from the sample by hand as much as possible. The soil moisture was determined as weight percentages of dry soil. Nitrogen mineralisation in the soil was investigated by the incubation method at the site and in laboratory conditions (Ellenberg 1964, Gerlach 1973, Runge 1970, 1971, Steubing

1965, Zöttl 1958, 1960). Ammonium nitrogen was determined according to Conway microdiffusion method (Steubing 1965) and the nitrate nitrogen according to the 2,4-xylenol method (Allen et al. 1974, Scharrer and Seibel 1956, Steubing 1965). The pH-value was determined electrometrically with a glass electrode and an ISKRA MA 5730 pH-meter. All spectrophotometrical analyses were made with a Beckman DB-GT spectrophotometer. The distribution of nitrogen mineralisation during the vegetation season was tested by Kolmogorov-Smirnov test with $\alpha = 0.05$ probability.

Results and Discussion

The natural mineral nitrogen content in the soil is not a measure for nitrogen supply of plant associations. It only represents the current difference between the nitrogen uptake and mineralisation in the soil. Mineral nitrogen can occur in the soil only on condition that the net mineralisation is greater than the plant uptake at the same time, and therefore it normally occurs in small quantities, especially in grassland soils (Klötzli 1969, 1975, Leuschner 1989, Rehder 1970). In those investigations the natural mineral nitrogen content occurred most frequently in early spring, which can be connected with the partial sterilisation in winter and the release of mineral nitrogen from the microbial biomass (Davy and Taylor 1974, Ehrhardt 1970, Williams 1969). Mineral nitrogen (Nmin) may sometimes occur in the soil in summer as a consequence of the reduced plant uptake (Leuschner 1989). Such a case was established in the investigations on plot 84. Figs. 2 and 3 show seasonal dynamics of natural Nmin content in the soil. Apart from that, the Kolmogorov-Smirnov test showed that the distribution of natural Nmin content significantly differed in both years of investigations ($D_{9,9} = 0.444 > D_{\alpha=0.05;\,9,9} = 0.430$).

Seasonal dynamics of nitrogen mineralisation on the stand shows great variability from date to date (Fig. 4 and 5). It is obvious that net nitrogen mineralisation in the soil was present throughout almost entire spring and summer of 1989. In that year a slow drop in mineralisation could also be noticed in summer, which was followed by a small rise. Such dynamic of nitrogen mineralisation was already often been noticed in earlier investigations (Clausnitzer 1983, Dierschke 1974, Rehder 1970). In 1990 the mineralisation dynamics was somewhat different at the beginning of the season. Nitrogen mineralised only in the form of ammonium, but later in May an extraordinary increase of nitrogen mineralisation occurred (Fig. 5). That sudden increase in mineralisation can be explained by the high temperature of the soil as a result of the fire on the bare surface. The renewal of vegetation on the plot, which was intensified due to the abundance of nitrogen was then followed by a temperature and mineralisation decline to the values similar to those recorded before the fire. Such a high increase of nitrogen mineralisation in the bare ground as much as three times that in the ground under vegetation, was recorded in some earlier investigations (Glavač and Koenies 1978). The Kolmogorov-Smirnov test esablished no significant difference in nitrogen mineralisation distributions in site between the two years of invenstigations ($D_{9,10} = 0.444 < D_{\alpha=0.05;\,9,10} = 0.578$).

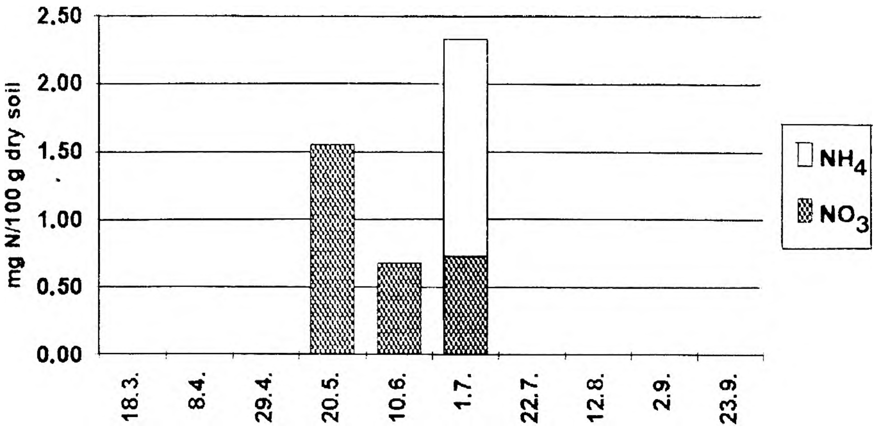

Fig. 2. Seasonal dynamics of field content of mineral nitrogen on permanent plot 84 in the 1989 season.

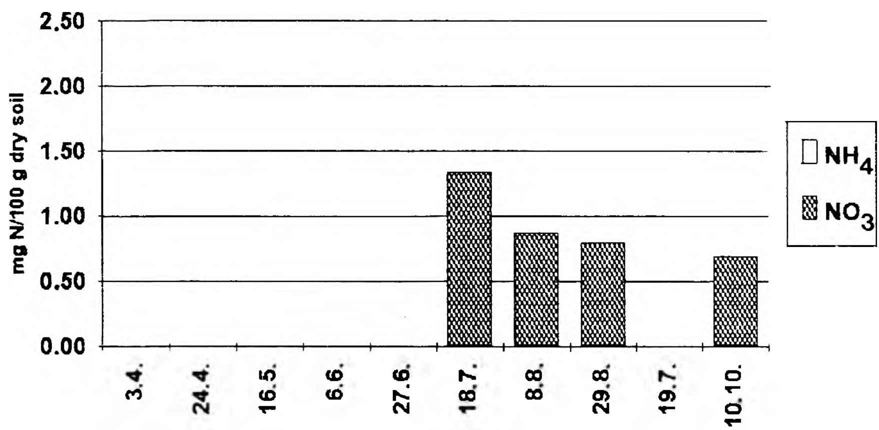

Fig. 3. Seasonal dynamics of field content of mineral nitrogen on permanent plot 84 in the 1990 season.

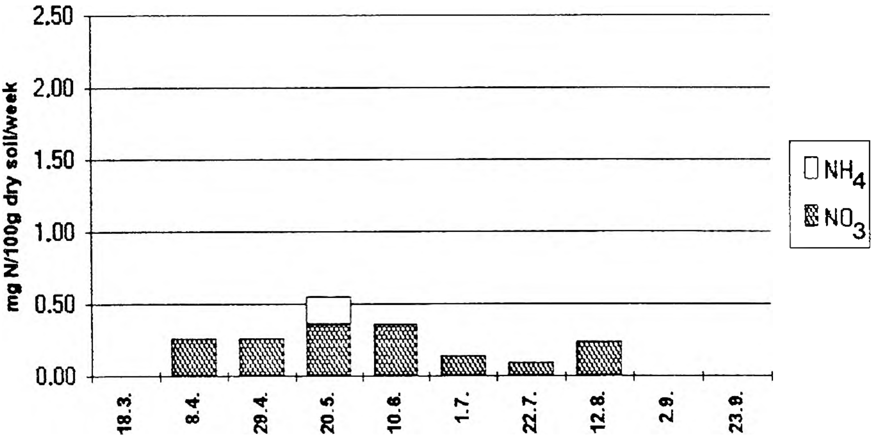

Fig. 4. Seasonal dynamics of nitrogen mineralisation on site at permanent plot 84 in 1989 season.

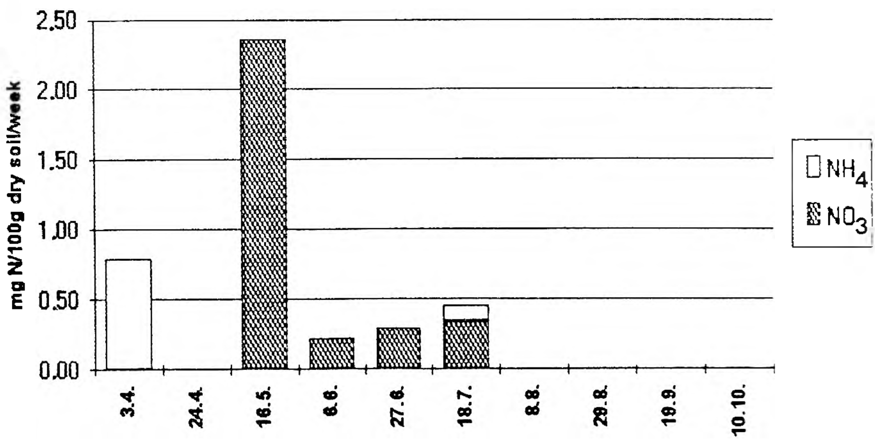

Fig. 5. Seasonal dynamics of nitrogen mineralisation on site at permanent plot 84 in 1990 season.

Nitrogen mineralisation under laboratory conditions in both years also showed a considerable variability from date to date (Figs. 6 and 7). The mineralisation intensity in relation to the mineralisation at the site was greater – on average 2.2 times. In 1990 net mineralisation in laboratory conditions was present on all sampling dates, while in 1989 it was absent in the April–May–July period (Fig. 6). The Kolmogorov-Smirnov test established that nitrogen mineralisation distributions in the laboratory significantly differed in the investigated years ($D_{10,10} = 0.607 > D_{\alpha=0.05;\,10,10} = 0.409$).

Seasonal soil moisture dynamics is shown in Figs. 8 and 9. In general the soil moisture was higher in 1989 (average 52,6%) than in 1990 (average 44.6%). The soil moisture was also more variable in the 1990 season than in 1989, which is demonstrated by the variance value of 11.5% in 1990 as against 5.8% in 1989. The lower average soil moisture was, at least partly, related to the reduced vegetation cover caused by fires that had occurred in that year. No direct connection between soil moisture dynamics and nitrification dynamics was established.

Soil temperature and moisture are considered to be the most important factors influencing the intensity of nitrogen mineralisation (Zöttl 1958, 1960). During the vegetation season they most frequently show cyclic changes and they could be expected to have an impact on cyclic changes in the mineralisation intensity. Nevertheless, in the majority of the investigations carried out so far such expectations did not materialise, and most frequently neither could the mineralisation intensity congruence with the temperature and moisture changes be established (Rehder 1970). A similar situation was also demonstrated in the attempts to connect mineralisation intensity to the dynamics of the microbial populations that participate in soil mineralisation processes (Burrichter 1958). The soil nitrogen mineralisation is also stimulated by the changes in the degree of decomposition and the amount of easily decomposable organic matter in the soil (Runge 1983). Therefore, the amount of mineralised nitrogen as the final result of the entire complex of mineralisation and immobilisation processes in the soil clearly varies considerably during the year, which was confirmed by the research on plot No. 84 (Figs. 4–7). The great variability of the results of the investigations is partly a result of the way of taking samples. The methods known and applied so far did not allow for taking samples twice at the same spot, and it is common knowledge that soil features can vary considerably at very small distances (Nykvist and Skyllberg 1989). Attempts were made to avoid or reduce the variability that occurs at sample taking by taking average sample of then "small" samples, but even that method did not fully remove that variability (Glavač and Koenies 1978). The only regularity that often reoccurs in investigations of seasonal nitrogen dynamics is the summer decline of mineralisation. That fall does not always come at the same time, but is most frequent in the July–August period (Clausnitzer 1983, Dierschke 1974, Rehder 1970, Runge 1970, 1971, Williams 1969) and is connected with the fall in the number of micro-organisms in that period (Burrichter 1958) and the decline in the quantity of easily decomposable organic matter in the soil (Runge 1983). Such a fall of mineralisation in summer was only partly confirmed in our investigations (Fig. 4).

The nitrification degree, i.e. the percentage of nitrate in mineral nitrogen, represents a special problem. It has already been emphasised that heaths are

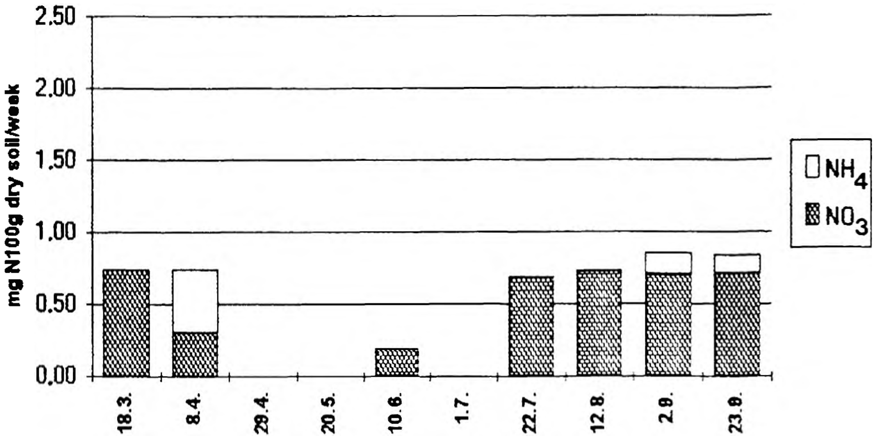

Fig. 6. Seasonal dynamics of nitrogen mineralisation in laboratory conditions in 1989 season.

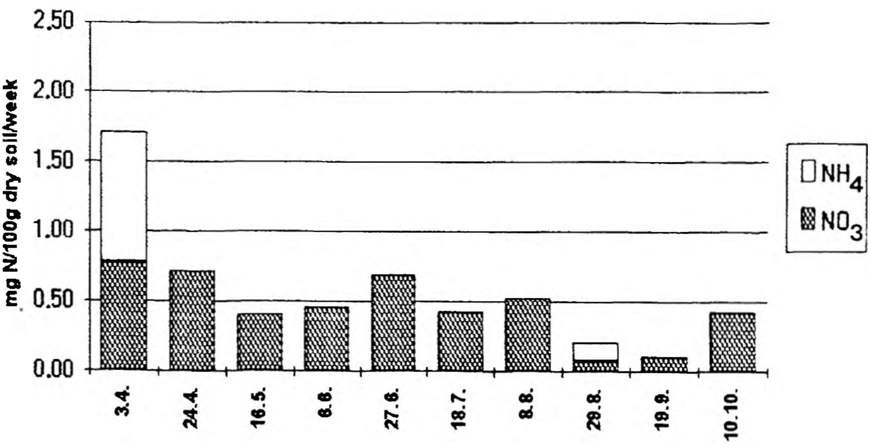

Fig. 7. Seasonal dynamics of nitrogen mineralisation in laboratory conditions in 1990 season.

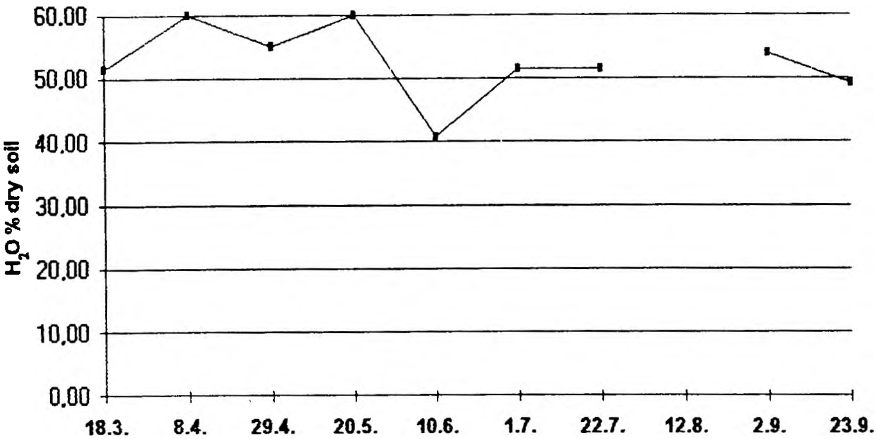

Fig. 8. Seasonal dynamics of soil moisture in 1989 season (in percentages of dry weight soil).

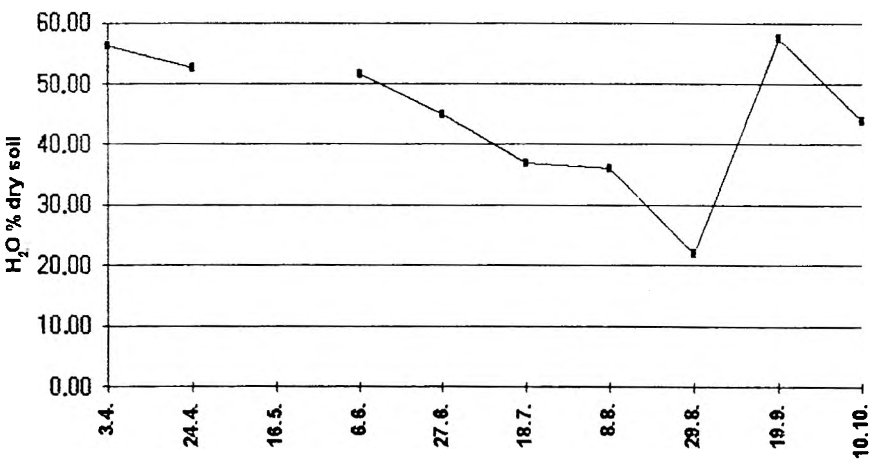

Fig. 9. Seasonal dynamics of soil moisture in 1990 season (in percentages of dry weight soil).

considered to be stands that are poor in mineral nitrogen (Lache 1976) and where nitrification does not occur (Kriebitzsch 1978). That opinion refers to the heaths of the sub-Atlantic region that develop on podzol soils (Ellenberg 1982, Kriebitzsch 1978). However, the heaths in the Illyrian region develop on very different types of soils – almost always on those with high acidity, but rarely on podzols (Gračanin 1931, Racz 1964, Horvat et al. 1974). The soil on plot No. 84 is a brown acid soil with a pH value of 4.95. Nevertheless, absence of grazing and fire, which are the major factors of developing and maintaining the heath type of vegetation (Horvat et al. 1974, Ellenberg 1982, Hofer 1967), produced great amounts of organic material that increased nitrification. The degree of nitrification in mineralisation in on site tests reached 90.5% in 1989 and 75.1% in 1990 (mean 82.8%), while in the laboratory conditions it was 87.6% on average. Such a high nitrate input certainly has an unfavourable influence on the heath vegetation. However, in humid climate areas, such as the Plitvice Lakes (Poje 1989), the nitrates will be leached from the soil after the removal of the organic mass from the surface, and both nitrification and nitrogen mineralisation will be reduced to the values appropriate for heath vegetation. Therefore, we consider the renewed anthropozoogenic influences (grazing and fire) that appeared unplanned on plot 84 had a positive impact on the maintenance of the *Genisto-Callunetum illyricum* heath vegetation. Unfortunately, in 1991 and later the access to this area as well as all further investigations of vegetation regeneration and the dynamics of the mineralisation processes in the soil were not possible any longer.

Conclusion

Permanent plot No. 84 is situated in the south-western part of the Plitvice Lakes National Park. Vegetation on the plot belongs to the *Genisto-Callunetum illyricum* Ht. 31 association (class *Nardo-Callunetea* Preising 49). A research into the seasonal dynamics of nitrogen mineralisation established the following:

1. The field mineral nitrogen content as well as the mineralisation on site and in laboratory significantly varied between sampling dates.
2. Seasonal dynamics of the natural mineral nitrogen content and mineralisation in laboratory was significantly different in the years of investigation, while the mineralisation on site was not significantly different according to the Kolmogorov-Smirnov test.
3. The fire that affected permanent plot No. 84 at the beginning of the 1990 season left the soil bare and increased the amount of easly decomposable matter and significantly increased the mineralisation intensity at the beginning of the season.
4. A great quantity of undecomposed organic matter that had accumulated in the course of 35 years of absence of anthropozoogenic influences on the plot's surface caused intensive nitrification.
5. The renewal of extensive grazing and fires removed the surplus of organic masses.

Appendix

Dates 89	H20%	NO3 mom.	NH4 mom.	NO3 st.	NH4 st.	NO3 lb.	NH_4 lb.	pH H_2O	ph KCl
18.3.	51.52	0.00	0.00			0.74	0.00		
8.4.	60.00	0.00	0.00	0.26	0.00	0.30	0.44	5.00	4.00
29.4.	55.04	0.00	0.00	0.26	0.00	0.00	0.00	4.85	3.89
20.5.	60.00	1.55	0.00	0.36	0.19	0.00	0.00	4.65	3.80
10.6.	40.85	0.68	0.00	0.36	0.00	0.19	0.00	5.20	4.00
1.7.	51.52	0.72	1.61	0.14	0.00	0.00	0.00	5.02	3.95
22.7.	51.52	0.00	0.00	0.09	0.00	0.69	0.00	4.90	3.90
12.8.				0.24	0.00	0.73	0.00	5.00	3.90
2.9.	53.85	0.00	0.00	0.00	0.00	0.70	0.15		
23.9.	49.25	0.00	0.00	0.00	0.00	0.71	0.13		

Dates 90	H20%	NO3 mom.	NH4 mom.	NO3 st.	NH4 st.	NO3 lb.	NH_4 lb.	pH H_2O	ph KCl
3.4.	56.25	0.00	0.00	0.00	0.79	0.78	0.93	4.81	4.03
24.4.	56.25	0.00	0.00	0.00	0.00	0.71	0.00	4.95	4.02
16.5.				2.36	0.00	0.41	0.00		
6.6.	51.51	0.00	0.00	0.22	0.00	0.46	0.00	4.92	3.98
27.6.	44.93	0.00	0.00	0.29	0.00	0.69	0.00	4.92	4.01
18.7.	36.99	1.34	0.00	0.34	0.11	0.43	0.00	4.95	4.02
8.8.	36.05	0.87	0.00	0.00	0.00	0.52	0.00	4.90	4.01
29.8.	21.95	0.79	0.00	0.00	0.00	0.08	0.13	5.06	4.04
19.9.	57.48	0.00	0.00	0.00	0.00	0.11	0.00	15.00	4.00
10.10.	43.88	0.69	0.00	0.00	0.00	0.43	0.00	5.13	4.05

H2O% soil moisture in % of dry weight
NO3 mom. field nitrate content in mg NO3-N/100 g dry soil
NH4 mom. field ammonium content in mg NH4-N/100 g dry soil
NO3 st. at the site mineralized nitrate -N in mg NO3-N/100 g dry soil/week
NH4 st. at the site mineralized ammonium-N in mg NH4-N/100 g dry soil/week
NO3 lb in laboratory mineralized nitrate -N in mg NO3-N/100 g dry soil/week
NH4 lb in laboratory mineralized ammonium -N in mg NH4-N/100 g dry soil/week
pH H2O soil pH in distilled water
pH KCl soil pH in 0,1 M KCl solution

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SAŽETAK

SEZONSKA DINAMIKA MINERALNOG DUŠIKA U TLU U ASOCIJACIJI *GENISTO-CALLUNETUM ILLYRICUM* Ht. 31 NA TRAJNOJ PLOHI 84 – NACIONALNI PARK PLITVICE (HRVATSKA)

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Sezonska dinamika mineralizacije dušika istraživana je u asocijaciji *Genisto-Callunetum illyricum* Ht. 31 (trajna ploha 84). Izostanak antropozoogenih utjecaja na plohi u razdoblju od 35 godina uvjetovao je nakupljanje velike količine organskog materijala i izmijenio izgled vegetacije. Istraživanje sezonske dinamike mineralizacije dušika provedeno je tijekom 1989. i 1990. godine metodom inkubacije na staništu i u laboratoriju. Utvrđena je velika varijabilnost mineralizacije dušika od termina do termina i u različitim godinama istraživanja. Ta varijabilnost uzrokovana je većim brojem vanjskih čimbenika kao i varijabilnošću uzoraka. Visoki stupanj nitrifikacije (do 90%), obično rijedak u vrištinskom tipu vegetacije, uzrokovan je najvjerojatnije velikom količinom organske tvari koja je nakupljena na površini plohe. Ispiranje nitrata u uvjetima humidne klime kakva je na području Plitvica te obnovljena ispaša i povremeni požari smanjit će količinu mineralnog dušika i postotak nitrata na razinu povoljnu za vrištinski tip vegetacije.

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