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Comprehensive assessment of factors influencing the flow of water and substances in soils of natural forest ecosystems

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The low level or air contamination in 1999–2007 allows to revise the relationship between changes of the chemical composition of natural water and the fluctuations of climate. Climate characteristics (duration of vegetation period), soil water flow and storage, filtration intensity and chemical composition were compared. Annual means of two integrated monitoring stations of natural territories in East and West Lithuania were used. Monthly means of soil water storage were related with soil water flow composition more closely than annual means.

The increasing soil temperature was the most marked change in 1999–2007. Duration of negative soil temperature became shorter, being one of the reasons for intensified water filtration in soil and the increasing content of nitrates, total nitrogen and organic carbon flow.

Key words: vegetation period, duration of negative soil temperature, soil water, flow, storage, nitrogen, organic carbon, pH, filtration, intensity

INTRODUCTION

Integrated monitoring stations in Lithuania were established for monitoring the global contamination, but it is necessary to revise changes in the chemical composition of soil water flow in relation with water regime and climate fluctuations.

Climate warming increases the intensity of material transformation processes and migration of substances in a geosystem. The global increase of temperatures has led to changes in soil regimes. The softening of climate conditions in some cases has resulted in a pronounced acidification of soil solutions, driven primarily by nitrification (Fitzhugh et al., 2003).

Results of a detailed monitoring show that, even in agrarian territories, the relationship between the annual averages of data obtained from the main meteorological stations and changes of hydrological and chemical properties of soil is weak (Mali auskas, Kutra, 2008). In forest ecosystems, application of generalized meteorological data is one of the factors predetermining a satisfactory correlation between the measured and the modelled characteristics (Samuila, 1999, 2000). More accurate predictions should be based on comprehensive data of monitoring stations.

Parameters of microarthropod populations are among the main indicators of soil formation reflecting the intensity of organic matter degradation. Yet the interpretations of data on soil organisms are controversial. There are opinions that the concentration of nitrogen compounds changes the abundance of microarthropod population (Augustaitis, Augustaitienė, Kliučius, 2008) and, in the conditions of optimal soil humidity, soil temperature exerts a minor influence on microarthropod abundance (Eitminavičiūtė, Matusevičiūtė, Augustaitis, 2008). It seems likely that in the first case (under a low pollution with nitrogen compounds) the increased concentration of nitrogen compounds in soil water results not from the increasing abundance of microarthropods but from a more intensive degradation of organic matter, i. e. a higher biological activity. In the second case, only one factor – thermal – can be taken into consideration. The hydrological characteristics (soil water volume, soil humidity) are of minor importance.

The aim of the present work was to analyse the influence of hydrological and thermal factors on migration of chemical substances in soil.

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OBJECTS AND METHODS

The study objects were soils of relatively natural forests of the Aukštaitija and Žemaitija Integrated Monitoring Stations (IMS LT01 and LT03). The Aukštaitija IMS territory includes the catchment of the small rivulet Versminis of the Ažvinčiai old coniferous forest reservation of the Aukštaitija National Park in the eastern part of Lithuania. The geographical co-ordinates: longitude 26°03′20′′– 26°04′50′′E, latitude 55°26′00′′– 55°26′53′′N. The Žemaitija IMS territory includes the catchment of the small rivulet Juodupis in the Plokštinės Old Coniferous Forest Reservation of the Žemaitija National Park in the western part of Lithuania. The geographical co-ordinates: longitude 21°51′56′′–21°53′10′′ E, latitude 56°00′19′′–56°01′05′′N (Fig. 1).

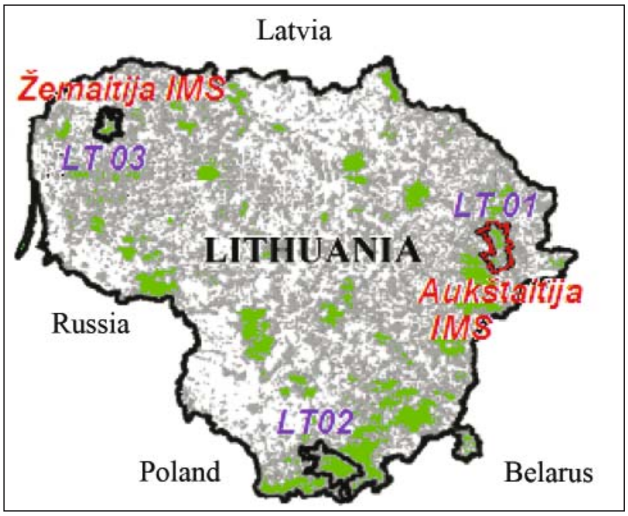

Fig. 1. Location of integrated monitoring stations (IMS) in Lithuania

Hills composed of gravel and stones of glacioaquatic accumulation are the prevailing rocks and relief in the Aukštaitija IMS. The prevailing soil is *Calcaric Arenosol*. Surface mineral horizon (0–10 cm) pH varies from 3.7 to 4.6, and in 10–20 cm the pH is about 5.0. Organic carbon content in the surface mineral soil horizon varies from 0.5 to 1.9% and total nitrogen from 0.07 to 0.13%. Vegetation is represented by coniferous (pine and spruce) and mixed forests. The humid habitat includes birch groves.

An undulating relief formed of glacioaquatic accumulations of limnoglacial sand with clay strata is dominant in the Žemaitija IMS territory. *Albic Arenosol* is the dominant soil. pH in the surface mineral horizon (0–10 cm) varies from 2.9 to 3.2, and in 10–20 cm the pH is about 3.7. The content of organic carbon in the surface mineral soil horizon varies from 0.4 to 2.0% and total nitrogen from 0.05 to 0.16%. Vegetation is represented by coniferous trees (spruce with 20% of pine). The humid habitat includes birch and elm groves.

Soil water was collected in plot plate type lysimeters (surface area 0.1 m^2) installed at a depth of 0.2 m. Averages from three lysimeters are presented. Soil water sampling was carried out every two months during the vegetation period. Methods of determining soil water chemistry are described in the Manual for Integrated Monitoring (1998). In the Aukštaitija IMS, plastic lysimeters were changed to stainless steel ones. In the Žemaitija IMS, lysimeters were plastic for all the monitoring period.

Soil water storage was detected gravimetrically (in LT03) and instrumentally (LT 01, barometric, "Watermark"). The lowest soil water content measured in the observation period was approaching the wilting point (empirical WP) and the highest was close to field capacity (empirical FC). Available soil water capacity (AWC) was counted as the difference between field capacity and wilting point.

A meteorological station was established near the Aukštaitija IMS in 1999. It is probably the only meteorological station of forest climate and soil temperature in Lithuania, working continuously for almost 10 years.

The climate of the region is moderately cold with high precipitation. According to the data from the Utena meteorological station, the long-term mean annual air temperature in open places is 5.8 °C. In 1999–2007, the air temperature average in the forest (near the lake) of the Aukštaitija IMS 2 m above the ground was higher by 0.6 °C, i. e. 6.4 °C. The difference of temperatures emerged as a natural result of forest acting as a climate milder.

The long-term annual precipitation in the region (Utena meteorological station) is 648 mm. In 1994–2007, in the forest near the lake it was 664 mm, i. e. higher by 2.5%. Comparison of the data from meteorological stations showed that the difference of precipitation in the forest and open areas up to 5–10% is typical (Bukantis, 1994).

The annual amount of precipitation during the observation period was growing, but the differences of highest and lowest precipitation of 3 year cycles in recent years were lower than at the beginning of observation. The difference between the highest and the lowest amounts of the precipitation cycles in 1994–2007 was gradually lowering from 39% (1996–1998) to 10% (2005–2007).

Soil temperature measurements were performed at the Aukštaitija IMS hourly at a depth of 0.05, 0.10 and 0.20 meters. Additionally, soil chilling events were measured every two weeks. The thickness of frozen soil was more than 1 cm.

Methods are described in the Manual for Integrated Monitoring (1998).

The correlation coeficient and the rank method were used for estimating the hydro-thermal factors.

RESULTS AND DISCUSSION

For examining the relationship among changes of climate, soil temperature and water filtration, first it was necessary to compare the flow of nitrogen compounds in the soil with their input from the atmosphere.

In the Aukštaitija IMS, the deposition of nitrate nitrogen fluctuated from 211 to 241 mg/m^2 per year, the highest deposition being observed in 2001–2002; depositions of ammonium were highest in 2006 (Augustaitis et al., 2007, 2008). Fluctuations of annual depositions of mineral nitrogen by wet precipitation in the Aukštaitija IMS did not exceed 15%.

In the Žemaitija IMS, the amount of nitrate nitrogen fluctuated from 342 to 414 mg/m^2 per year, and the highest amounts were observed in 1998 and 2002. Ammonium nitrogen of in the Žemaitija IMS was highest in 2001 and 2004 (Augustaitis et al., 2007, 2008). The highest fluctuations of the annual depositions of mineral nitrogen by wet precipitation in the Žemaitija IMS amounted to about 20%.

The highest flow of nitrogen in soil does not coincide with deposition by precipitation. Periods 2004–2006 in the Aukštaitija IMS and 2005–2006 in the Žemaitija IMS were different in comparison with the beginning of monitoring and 2007 (Tables 1 and 2). In the Aukštaitija IMS, the flow of nitrates in 2004 and 2005 increased more than three times, and the total nitrogen increased several times in 2004–2006. The amount of organic carbon in 2005–2007 was higher about three times as compared with 2003 when the measurement of organic carbon was started. Soil water pH increased in comparison with the average value by two units in the Aukštaitija IMS (Table 1). It was affected partly by the reinstallation of lysimeters.

Table 1. **Properties of soil water flow in the Auk taitija IMS. Data in shaded cells are higher than the average values for 1999–2003 by more than 50%**

Properties of soil water flow	Volume, mm	N of NO_3, g/m^2	N of NH_4^+, g/m^2	Total N, g/m^2	Total C organic g/m^2	pH
1999	99	19	4	108		4.40
2000	134	6	7	116		4.56
2001	68	10	8	70		4.54
2002	112	8	15	101		4.61
2003	53	5	3	32	1401	5.29
2004	66	55	3	123	2207	7.09
2005	129	69	5	233	2320	7.06
2006	77	20	4	155	3538	7.06
2007	71	9	2	81	2531	6.96

Table 2. **Properties of soil water flow in the Žemaitija IMS. Data in shaded cells are higher than average for 1999–2003 by more than 50%**

Properties of soil water flow	Volume, mm	N of NO_3, g/m^2	N of NH_4^+, g/m^2	Total N, g/m^2	Total C organic g/m^2	pH
1999	117	11	14	312		4.17
2000	134	11	15	121		4.10
2001	247	24	28	323		4.09
2002	195	13	23	239		4.28
2003	137	18	13	148	5664	3,95
2004	139	7	9	138	6175	3.83
2005	265	20	38	356	8350	4.03
2006	330	19	60	616	10196	4.37
2007	263	15	28	384	10792	4.10

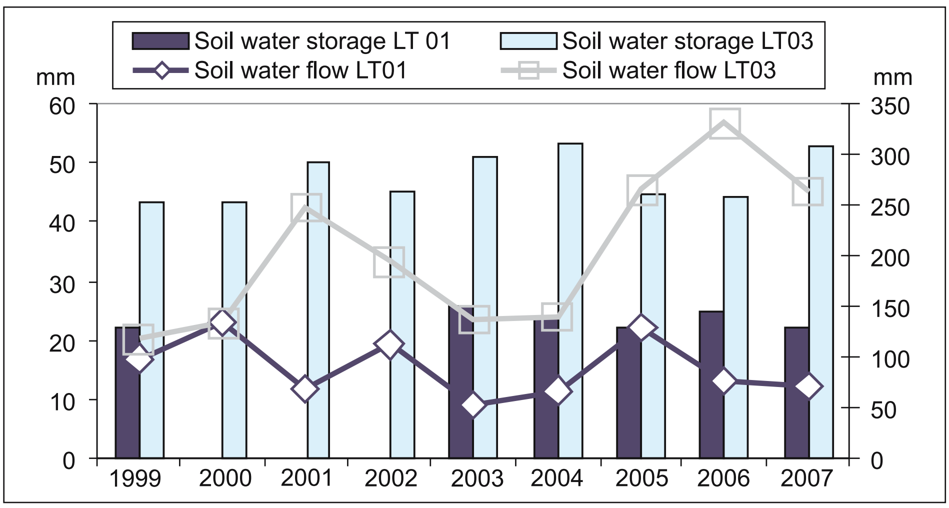

Fig. 2. Soil water volume and storage in Aukštaitija (LT01) and Žemaitija (LT03) IMS

The soil water pH, nitrogen and organic carbon in the Žemaitija IMS changed in 2003–2006 too, though lysimeters were not reinstalled. Soil water acidity increased in 2003–2004 by 0.13–0.25 pH units and in 2006 decreased in comparison with the average value by 0.3 units. The flow of nitrates in 2005 and 2006 increased by 30–50%, and total nitrogen in 2006 reached 200% from the average. The content of organic carbon in 2005–2007 increased about twice (Table 2).

If nitrogen flow with precipitation fluctuated by 15–20%, what processes were responsible for the wide fluctuations of soil water composition?

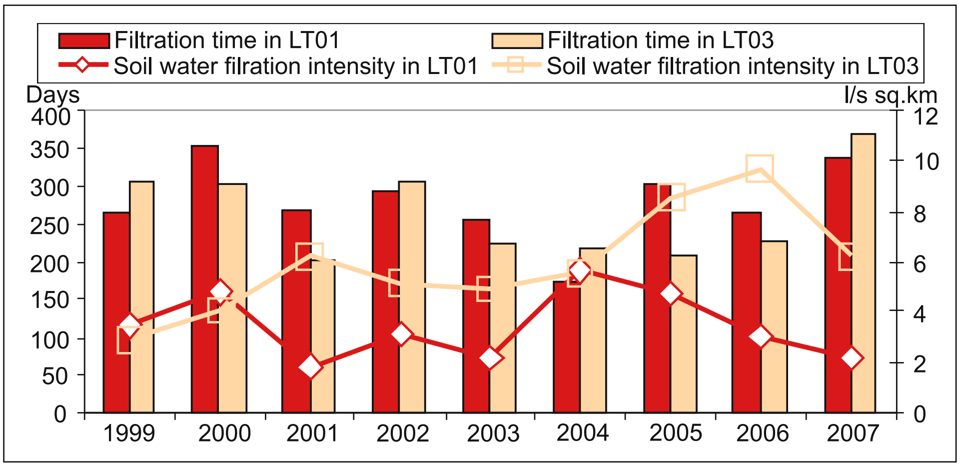

Fig. 3. Soil water filtration characteristics at Aukštaitija (LT01) and Žemaitija (LT03) IMS.

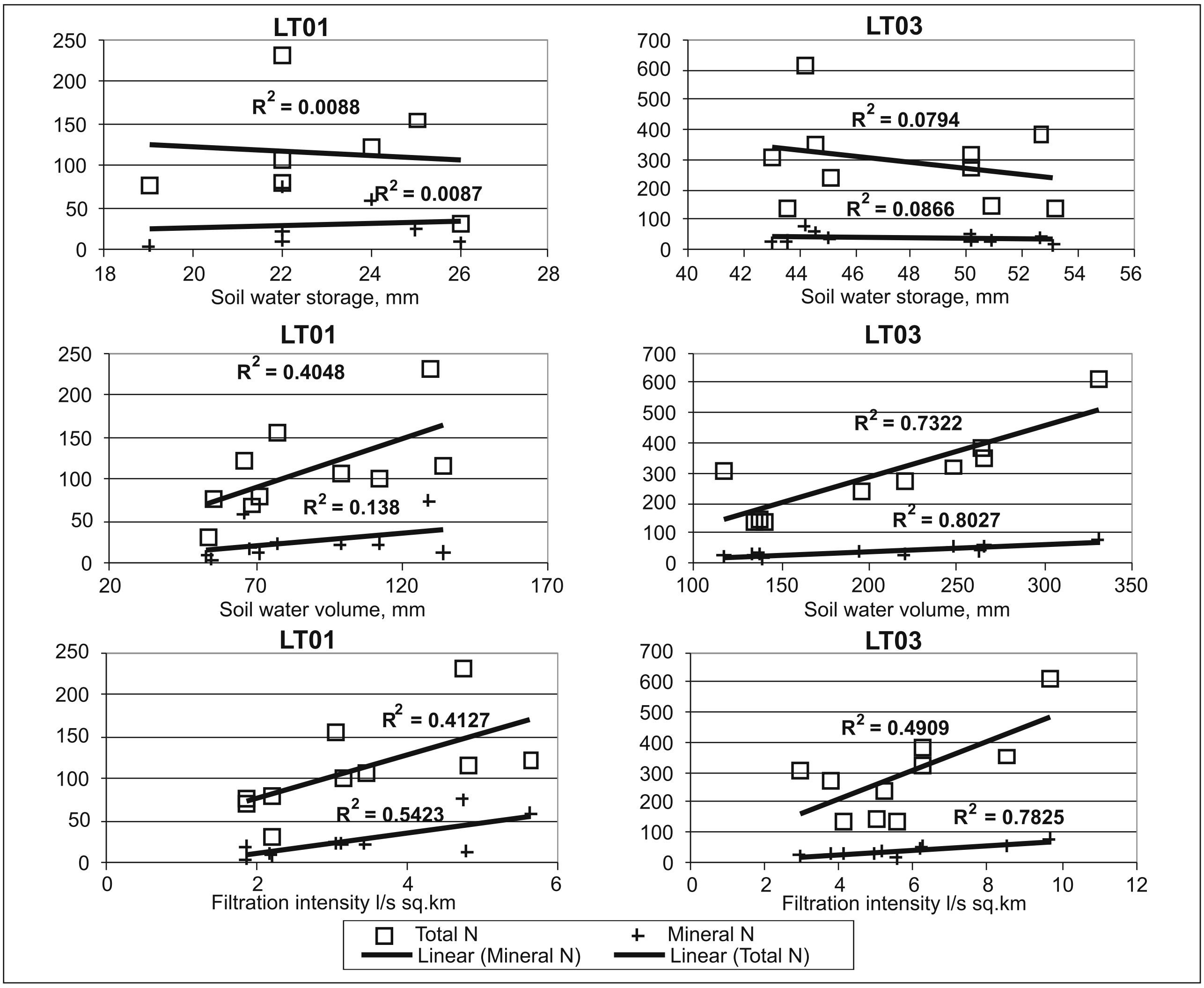

Fig. 4. Correlation between annual average soil water volume, storage filtration intensity with total and mineral nitrogen flow in soil layer 0–20 cm

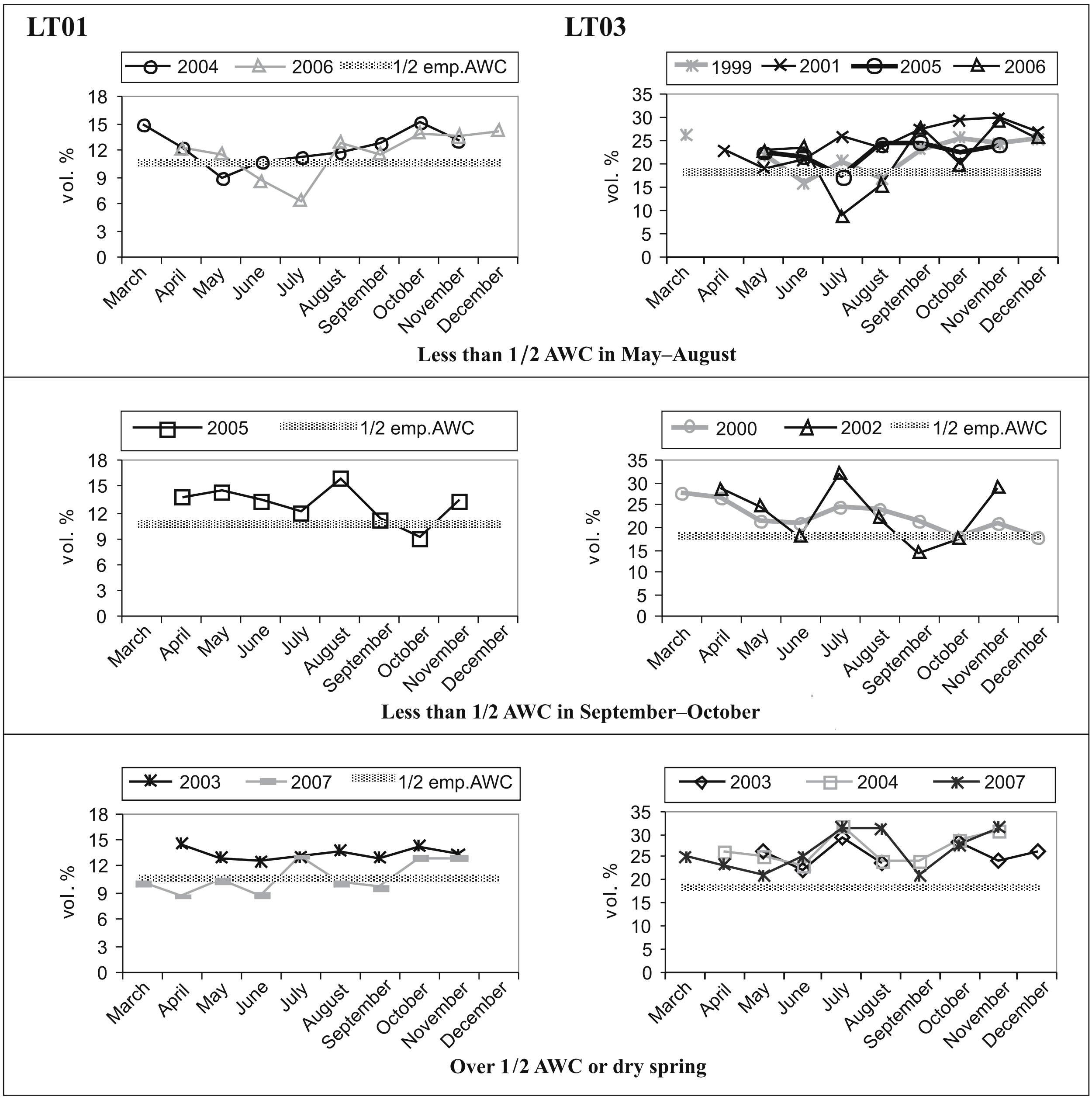

Fig. 5. Grouping of soil water storage regimes

In 2005, the soil water storage and flow data in both monitoring stations and additionally in 2006 in the Žemaitija IMS differed from the values for the earlier and later years. The lowest soil water storage was coincident with one of the highest soil water flows in the observation period (Fig. 2). This can happen in soil with many cracks. Soil cracking and increased soluble organic carbon flow (Tables 1 and 2) can be a result of intensifying organic matter decomposition.

Among the reasons for the low soil water storage, we can mention the short duration of negative soil temperatures in mild winters when the soil is weakly frozen and water percolation in it is too weak for refilling the soil water storage.

In LT01, soil water filtration intensity was related to the flow of nitrogen compounds more closely than soil water flow volume and storage, but the relationship wasn't very close. The relationships were stronger in LT03 than in LT01 (Fig. 4).

Although the coefficients of correlation between annual means of soil water storage and the flow of nitrogen compounds are the lowest, this doesn't mean the absence of any relationship between these characteristics. The grouping of soil water storage regimes by monthly fluctuations demonstrates that the most intensive flow of nitrogen compounds proceeds when soil water storage is greater than half of the available water capacity (½ AWC) in spring and autumn, but low in late spring or summer (Fig. 5, Tables 1 and 2).

For evaluating the thermal factors, only data of the LT01 were available.

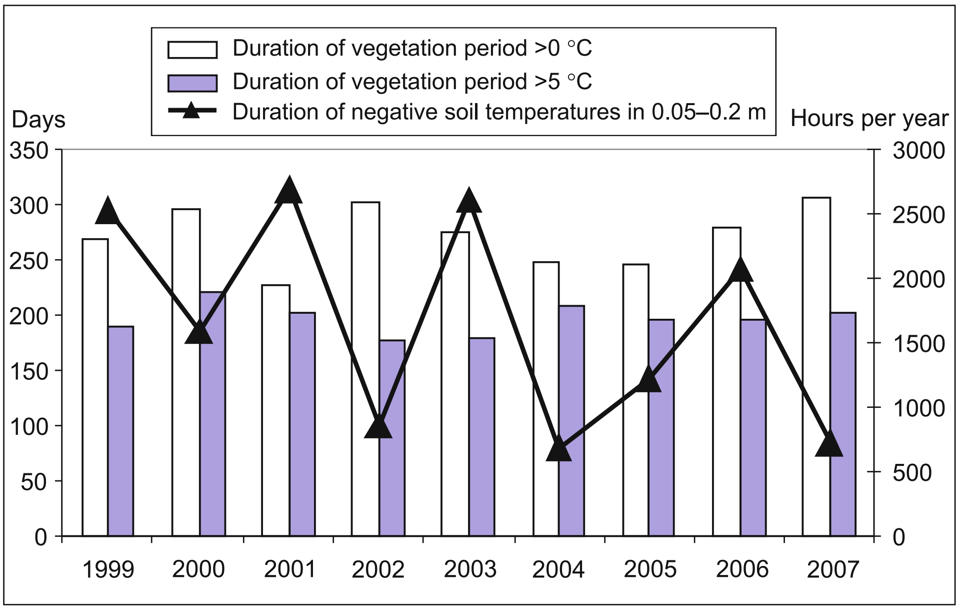

Fig. 6. Relationship between the duration of vegetation period and negative soil temperatures

Table 3. **System of hydro-thermal factors ranks for the LT01**

Year	Thermal ranks				Hydrological rank	Total sum rank	Total nitrogen flow rank
	Soil temperature		Soil frost expansion	Sum rank			
	Average	Amplitude			Filtration		
1999	6	9	7	1	6	3	5
2000	8	8	4	2	8	5	6
2001	6	7	6	3	1	1	2
2002	4	6	2	6	5	7	4
2003	1	3	9	5	3	4	1
2004	2	1	1	9	9	9	7
2005	5	4	3	6	7	8	9
2006	2	2	8	6	4	5	8
2007	8	5	5	4	2	2	3

The following two characteristics were compared: duration of vegetation period and duration of negative soil temperatures (at a depth of 0.05, 0.1 and 0.2 m). Most often, the relationship was negative both in 1999–2002 and in 2007. In 2002 and 2007, the duration of negative soil temperatures was the shortest and the vegetation periods (>0 °C) were the longest. However, in 2003 the long duration of the vegetation period (>0 °C) coincided with the long-lasting negative soil temperatures, and the soil was frozen deepest. Later, in 2004 and 2005, on the contrary, the short vegetation period (>0 °C) was not followed by long-lasting negative soil temperatures, but the duration of the vegetation period (>5 °C) was comparatively long (Fig. 6).

Soil microarthropod density at the LT01 monitoring station was highest in 2005 and lowest in 2003 (Eitminavičiūtė, Matusevičiūtė, Augustaitis, 2008). The reason for it was a favourable soil water storage regime in 2005 and the long duration of negative temperatures in the cold winter of 2003 (Fig. 5).

The final result of the investigation is grouping of the hydrological and thermal factors (annual means) by importance for soil processes. The highest ranks mean the highest influence for substance decomposition and movement: high soil temperature, low soil temperature ampiltude, insignificant frost expansion (Table 3).

Filtration intensity is important for the Aukštaitija IMS, and in Žemaitija soil water volume can be used for hydrological rankink because the climate of Aukštaitija is more continental.

CONCLUSIONS

The most remarkable increase of nitrogen in soil water was coincident with the high volume (LT03) and filtration intensity (LT01) of soil water, but the relationship was not direct. Soil water storage regime and thermal factors influence the rate of soil processes, too.

The periods of high volume and filtration intensity of soil water at the Aukštaitija IMS occurred after a year with the widest fluctuations of temperatures and in the period when the duration of negative soil temperatures and of the vegetation period (>0 °C) was short.

A high total organic carbon flow follows the highest total nitrogen washing out from the soil without increasing water volume and filtration intensity.

A ranking system was compiled for evaluating the influence of both hydrological and thermal factors on the intensity of total nitrogen migration in soil 0–20 cm layer at the Aukštaitija Integrated Monitoring Station.

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IŠSAMUS NATŪRALIŲ MIŠKO EKOSISTEMŲ DIRVOŽEMIŲ VANDENS IR CHEMINIŲ JUNGINIŲ KAITOS VEIKSNIŲ ĮVERTINIMAS

S a n t r a u k a

Esant nedideliam natūralių miško ekosistemų teršimui, globalaus integruoto monitoringo stotyse (IMS) buvo analizuojama klimato kaitos įtaka vandens ir cheminių medžiagų srautui dirvožemyje. Apskaičiuoti ir palyginti Lietuvos santykinai natūralių ekosistemų IMS Aukštaitijoje (LT01) ir Žemaitijoje (LT03) 1999–2007 m. dirvožemio hidrologijos, azoto bei organinių junginių išnešimo parametrai.

Aukštaitijos IMS didžiausias pH ir azoto bei organinės anglies srautas dirvožemyje užfiksuotas 2004–2006 m. Nustatyta, kad kontrastingomis 2003 m. klimato sąlygomis, esant aukščiausiai per stebėjimo laikotarpį vidutinei dirvožemio temperatūrai, neigiamų temperatūrų trukmė buvo ilgiausia, o dirvožemio vandens srautas ir intensyvumas – vieni mažesnių per stebėjimo laikotarpį. Tai galėjo lemti ypač mažas 2004 m. dirvožemio vandens atsargas, didelį srauto intensyvumą, todėl, nepaisant mažo dirvožemio vandens tūrio, azoto ir organinės anglies išplauta keletą kartų daugiau nei vidutiniškai. Daug organinės anglies išplauta ir 2007 m., nors vandens srautas sumažėjo. Modeliuojant dirvožemio geocheminius parametrus, turėtų būti atsižvelgta ir į hidrologinius parametrus, ir į informatyviausias šilumines charakteristikas. Ypač informatyvūs yra temperatūros amplitudės ir neigiamų temperatūrų trukmės parametrai.

Raktažodžiai: vegetacijos periodas, neigiama dirvožemio temperatūra, dirvožemio vanduo, srautas, išlaikymas, azotas, organinė anglis, pH, filtracija, intensyvumas