The Impact of Hydrotechnical Drainage on the Cycle of Some Biogenous Elements in Forest

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When searching for environment friendly solutions to achieve higher economic efficiency in forest management, we have so far neglected the impact of woodland hydrotechnical drainage on the fertility of forest soils, including the content of biogenous elements in watercourses. To find reasonable answers to the issue of the cycle of some biogenous elements in drained forests, the related research work was resumed in 1997 at the *Vesetnieki* Station of Permanent Ecological Research for the following: regular assessement of the precipitation water quality in an open place, under forest canopy,.the water quality in soil groundwaters, in ditch runoff and in the *Veseta* river. The field data are compared with those obtained on the same sites between 1966 and 1974. The data show only the concentration of $N\text{-}NO_3$ in the soil groundwater to have increased from 0.1 mg/l to 0.5 mg/l over 30 years. The change of pH number from 5.97 to 6.72 is statistically significant. The input of N, P and K ions into the forest ecosystem by the precipitation waters over a year–long period exceeds the output of the same substances by ditch runoff. This is true for both forests on a deep layer of peat and those on hydromorphic mineral soils.

Key words: hydrological parameters, forest drainage, biogenous elements.

Introduction

Proceeding from forest growth conditions the Latvia's woodlands fall into five distinct site type classes:

• Woodlands with dry mineral soils (54.5%), lacking a thick layer of raw humus on the upper soil surface; soil agrochemical properties determine the soil fertility; the groundwater lies deep and has no effect on soil aeration.

• Woodlands with wet mineral soils (10.4%); in wet summers the groundwater reaches the root horizon, making difficult soil aeration and promoting gley formation; a 30 cm thick layer of raw peat or organic matter may form; moisture–tolerant species appear in the ground cover vegetation.

• Woodlands with wet peaty soils (18%); the organic soil or peat layer is over 30 cm thick; sometimes the thickness of peat layer may reach 5 m; stand productivity goes with the intensity of groundwater pressure discharge, enriching the soil with mineral nutrients.

• Woodlands with drained mineral soils (9.6%); tree growth does not depend on soil aeration; the layer of raw organic matter or peat is no more than 20 cm thick.

• Woodlands with drained peaty soils; this class represents swamp or forests on wet peaty soils as they develop after drainage; the soil aeration is good; the forest litter, accumulating after drainage, gradually forms a fertile topsoil layer permeated by tree roots; the thickness of peat layer is above 20 cm.

The productivity of wetland forests on average is increased by drainage: for spruce four times, for pine three times, for birch – twice, for black alder – 1.5 times. In Latvia, the changes in forest productivity, resulting from the hydrotechnical drainage of woodlands, have been studied by numerous scientists for more than 100 years (Ostwald, 1878). The aim has been to identity both the causes of forest degradation and assess the silvicultural effect of hydrotechnical drainage (Markus, 1936; Bušs, 1981; Zālītis 1983, in Russian). A number of regularities may be deduced from the research results of the above authors: 1) hydrogeological conditions rather than the precipitation, exceeding evaporation, is the chief cause of swamping; 2) no negative impact of the hydrotechnical drainage on forest productivity is ever observed; 3) the silvicultural effect of drainage is observed considerably further away from the ditch than the range over which the groundwater table subsides.

Research results on the regularities that exist between the forest productivity and woodland biological diversity show the ecological differences of wetland forests to depend on the geoclimatic conditions in the locality rather than on the share of wetland forests drained there (Zālītis, 1996). In Latvia, from the standpoint of biological diversity conservation, it is expedient to drain 70% of all wetland forests. It means that in addition to the forest lands already drained, a surplus of 280,000 hectares is still to be drained. This will improve radically both the water regulatory functions of forest and the carbon absortion / oxygen release by it.

The hydrotechnical drainage most immediately affects the soil and waters. As convincingly proved in a monograph on the impact of hydrotechnical drainage on the environment (Šķiņķis, 1992), the drainage of wetlands, going to be used for farming, affects the environment much stronger than that of wetland forests. However, a number of topical issues related to woodland drainage still remain unsolved: to what extent the biogenous elements, released in peat decomposition, are entrapped by the cycle of matter in the forest ecosystem; what amount of them flows away by ditches; how the content of biogenous elements in ditches and water reservoirs varies. In search for answers to these questions we have in this effort attempted to conduct an analysis of the long-term field data of the *Vesetnieki* Station of Permanent Ecological Research.

Materials and methods

At *Vesetnieki* continuous observations of the post-drainage changes in the forest stand structure and hydrological regime have been made since 1963. The experimental area, totalling 410 ha, was drained in 1960 by laying out a network of ditches and closed drainage. It comprises both forests over a deep layer of peat (peat layer depth 5.5 m, area, 150 ha) and a shallow one (depth up to 0.2 m, area 150 ha), as well as woodlands with dry mineral soils (100 ha) and a small area of undrained forest (10 ha) over a deep layer of peat, used for the control to compare the on-going processes in drained and undrained forests. In the undrained forest the stock volume over the past 40 years remained constant (40 m^3/ha), whereas on the drained sites in peaty soils it has grown up to 292 m^3/ha (the data of 1999) (Fig.1). Over this period, both phytocenoses and soils have changed significantly; in the topsoil, up to the depth of 10 cm, a new, well–aerated layer of forest litter, decomposed up to 50%, has emerged, which is still followed by a well preserved, slightly decomposed (about 10%) sphagnum layer (Fig.2).

In the experimental area a follow–up of the following hydrological and hydrogeological parameters is going on for the 37[th] year: measurements of groundwater table (after every 10 days in 320 observation wells),

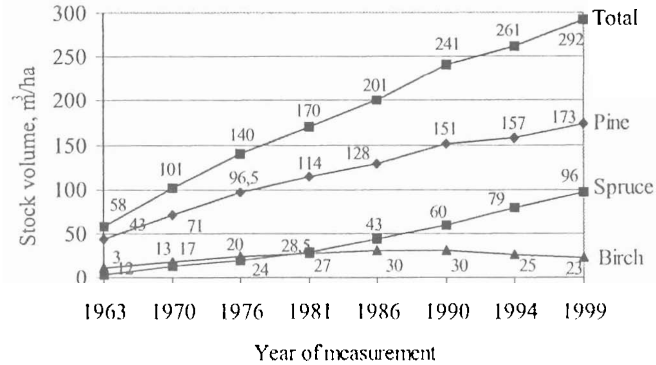

Figure 1. Post – drainage variations of forest stock volume over time.

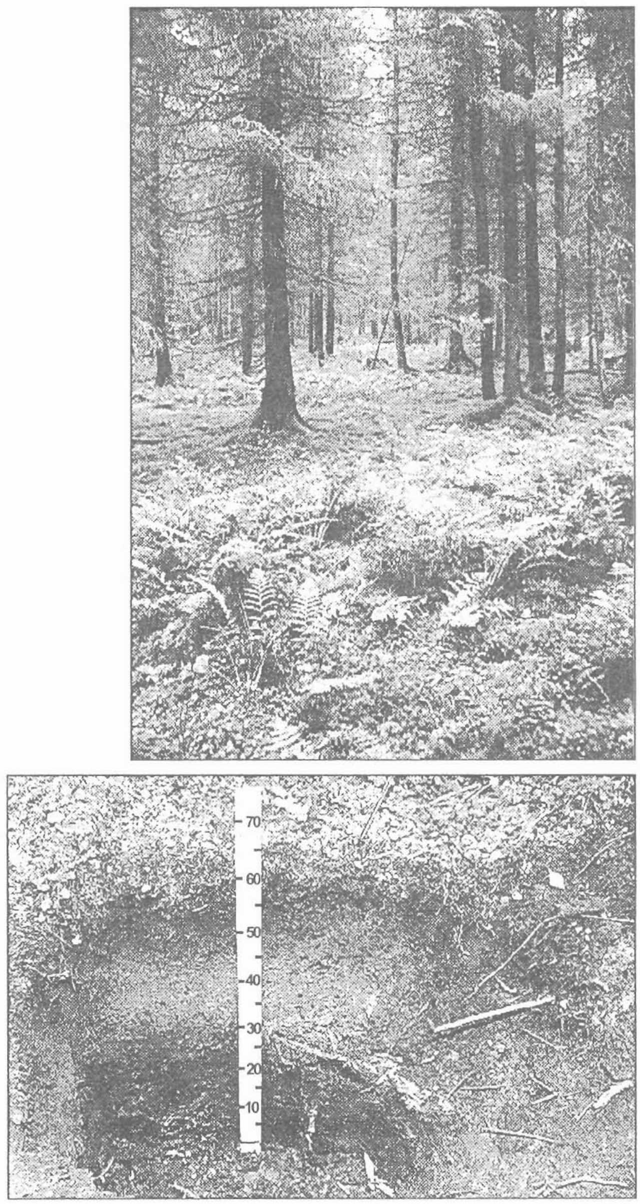

Figure 2. Forest stand and soil in a drained forest on a deep layer of peat 40 years ago. (Photo Tālis Gaitnieks)

piezometric level of subsoil water discharge (35 wells), water runoff (5 hydrometric posts), precipitation water, reaching the soil (in 125 points), snow cover parameters (in 10 forest stands differing in structure); groundwater chemical composition in peaty soils was analysed repeatedly between 1996 and 1974 (unpublished data of I.Spalviņa, of LFRI "Silava") by detecting the content of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, Ca^{2+} and pH.

In April, 1997, the research on the cycle of biogenous substances in drained forests was resumed in order to establish the input / output ratio of biogenous substances, their concentration in the atmospheric precipitation, soil groundwater and ditch runoff. The quality and quantity of precipitation water, reaching the forest ecosystem, are analysed twice a month by using the water of 25 precipitation collectors (the size of collecting surface 100 cm^2; the deployment of precipitation collectors is as follows: 5 – in an open area, including 1 – at the station,s centre, 4 – around the perimeter of the experimental area at a distance of 1.5 km from the station,s centre; 20 – in the forest stands of pine, spruce and birch, as well as in a young stand of conifers; in each stand 5 precipitation collectors are positioned. To calculate the water output, samples (1,000 cm^3) are taken at each of the 5 hydrometric posts; in 3 of them ditch runoff water, cought over areas having a deep layer of peat, are measured; the remaining 2 hydrometric posts cover the areas of hydromorphic mineral soils. To establish the so called background changes, water samples from 18 groundwater measurement wells and 3 subsoil water wells, up to 30 m deep, are analysed. Since the time the given research was resumed, the total number of soil analyses conducted at LFRI „Silava" is 9,692, covering 32 replications of sampling. The concentration of nitrogen, phosphorus and potassium in the samples of water was determined by the photometric method, that of calcium and magnesium – by titration by Trilon B.

Results

In drained woodlands on deep peaty soils, the input of biogenous elements into the ecosystem is predominantly by precipitation water containing the respective substances, complemented by the dust, accumulated by trees and washed off by precipitation. Waters coming from the adjoining dry site forests as well as those of the subsoil water pressure discharge represent another source of input. The forest phytocenosis of hydromorphic mineral soils may partly use up the elements of the mineral soil structure.

Post–drainage variations in both the soil fertility and the aquatic ecosystem may roughly be described by the input/output ratio of biogenous elements, first of all – by the input via atmospheric precipitation and the output by ditches.

It is noted that the amount of precipitation, on a fortnight basis on the relatively small territory of *Vesetnieki*, may vary considerably. For example, the amount of precipitation over a significantly rainy period from August 9, 1988 till August 24, 1988, recorded at 5 precipitation collectors located in the open area at a distance no more than 3 km between them, was the following (mm): 83.6; 87.7; 85.4; 84.0 and 80.2, the arithmetic mean 84.1 mm, standard deviation s = 2.7 mm, with a deviation of individual measurements from the arithmetic mean ± 4.5 mm at the 95% probability level. The same data for a considerably rainless period from June 6, 1999 till June 21, 1999 were the following (mm): 34.1; 31.3; 46.2; 36.7; 32.5; the arithmetic mean 36.2 mm; standard deviation s = 6.0 mm; deviation of arithmetic mean ± 9.9 mm at the 95% probability level. The above examples are believed to demostrate convincingly the differences in the amount of precipitation observed over a relatively small territory, especially in dry summers. The fluctuations in the amount of precipitations were evaluated as stochastic, and the credibility of the estimates was increased by prolonging the period for which the balance of the substances analysed was calculated.When the estimates for calculating the mentioned balance are based on the data covering a longer period, it is possible to avoid the impact of error, likely to occur with the laboratory measurements of the concentration of biogenous elements in the samples collected. Unfortunotely, the data body for the concentration (mg/l) of biogenous substances shows no regular distribution over time. By contrast, a distinguished left asymmetry is typical of individual sets of data, i.e. predominance of cases showing a low concentration of the corresponding substance. For example, for the data set, covering a period from July 1, 1998 till June 30, 1999 and comprising 78 measurements, the arithmetic mean for the concentration of $N\text{-}NH_4^+$ is 1,4 mg/l, standard deviation s = 1,6 mg/l; for Ca^{2+} the arithmetic mean concentration is 5.2 mg/l, standard deviation s = 6.3 mg/l. Providing the distribution over time of the concentration of substances analysed is so asymmetric, it is not possible to estimate the substance input just by multiplying the arithmetic mean concentrations by the amount of precipitation over a longer period – the season or year. In this effort, the input of substances was estimated for each individual period, roughly a forthight long, and in order to get results on a yearly basis, those of individual periods were summed up.

The amount of nutrients reaching the forest soil and, consequently, becoming the input to the balance of biogenous elements, may be substantially affected by the territorial redistribution of the precipitation inside the forest stand during the rain, as well as by the variations in precipitation water quality. The observations and the measurements of hydrological parameters continue, and it is believed that reasons for so wide a fluctuation in the concentration of biogenous elements in the forest ecosystems will ultimately be identified. The questions to be answered may be put as follows: to what extent the data dispersion depends on the amount of precipitation, the precipitation intensity during each individual case of rain, the number of rainy days over a definite period of time, and stand structure. We believe the answers to these questions are important to enable modelling the cycle of biogenous substances also over a year–long period after ditching. A mechanical extrapolation of the data obtained over the time is impeded by some unexpected facts. For instance, the concentration of $N\text{-}NH_4^+$ in the runoff water increases along with an increase in ditch runoff (Fig.3). Most probably it is due to a weakened soil aeration and increased concentration of ammonium ions in the topsoil layer during a heavy rain, resulting in a more intensive

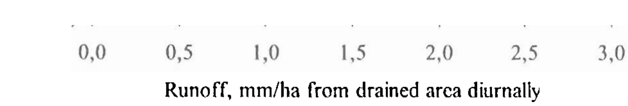

Figure 3. $N\text{-}NH_4^+$ concentration in the ditch runoff waters as dependent upon the amount of runoff in the forests on peaty soils.

runoff and, consequently, washing the ammonium ions off to ditches.

In the given work, the input of biogenous elements, for each of 5 catchments, is estimated on a fortnight basis as the weighted arithmetic means in line with the forest structure for each catchment.

The flow of precipitation water through the forest canopy results in a slight reduction of the concentration of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ and an increase in K^+ concentration; no significant differences in the concentration of Ca^{2+} and Mg^{2+} as well as in pH number (pH 6.51 in an open area, pH 6.31- in the forest) are observed; cf: pH in ditch water from the forests on peaty soils – 7.32; from the forests on hydromorphic mineral soils – 7.44; at *Veseta*, draining off the subsoil layers of the experimental area – 8.03.

When analysing the impact of woodland hyrotechnical drainage on the cycle of biogenous elements, it is expedient to make a comparision between the amount of substance input and that of output via ditches (Fig. 4 to 9), both in woodlands on peaty soils (Catchment 1 to 3) and those on hydromorphic mineral soils (Catchment 4 to 5).

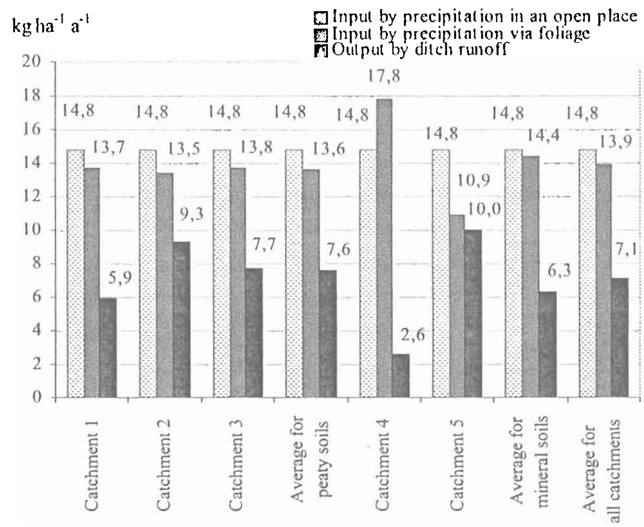

Figure 4. $N\text{-}NH_4^+$ balance 01.07.98 – 30.06.99.

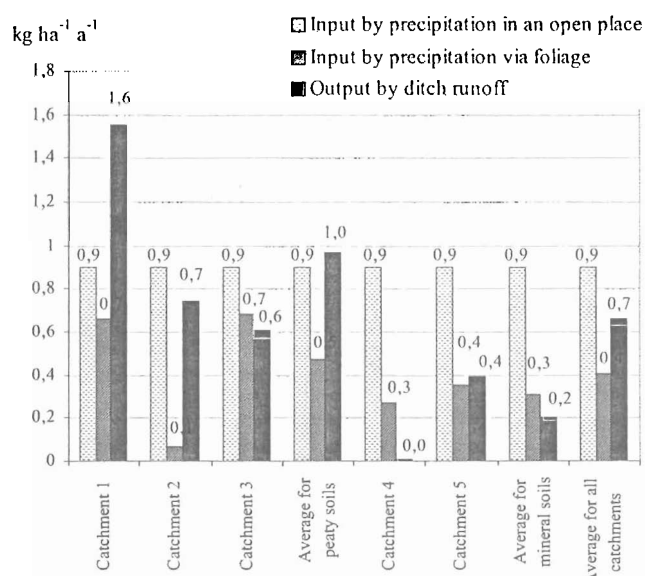

Figure 5. $N\text{-}NO_3^-$ balance 01.07.98 – 30.06.99.

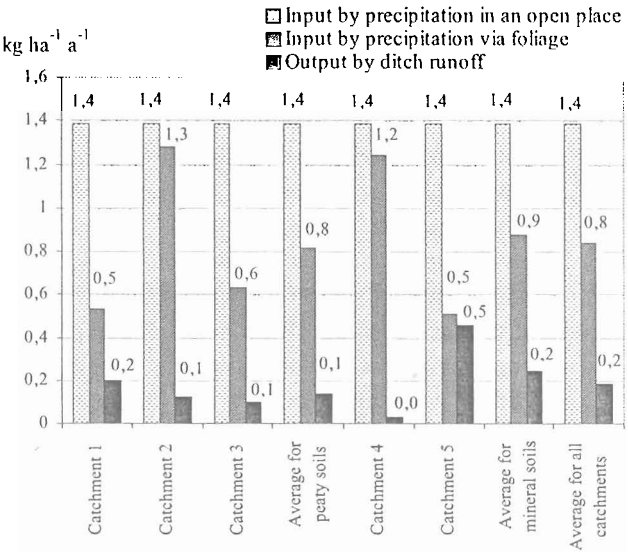

Figure 6. P-PO_4^{3-} balance 01.07.98 – 30.06.99.

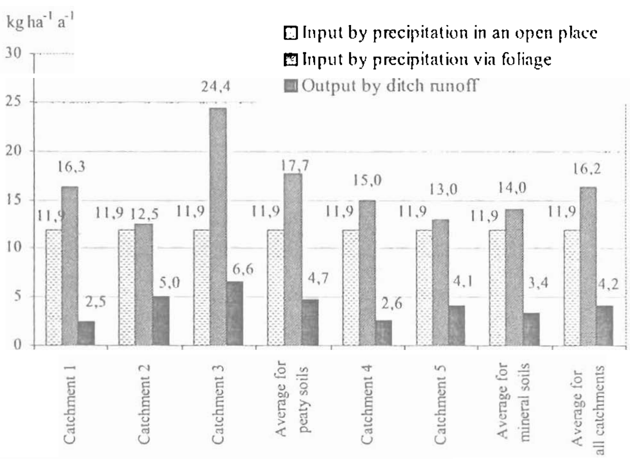

Figure 7. K^+ balance 01.07.98 – 30.06.99.

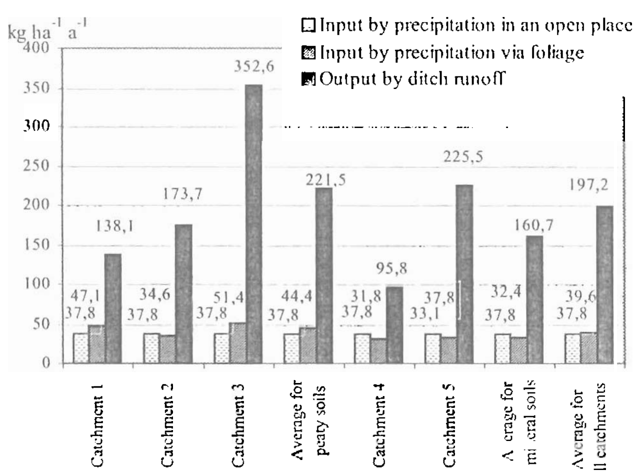

Figure 8. Ca^{2+} balance 01.07.98 – 30.06.99.

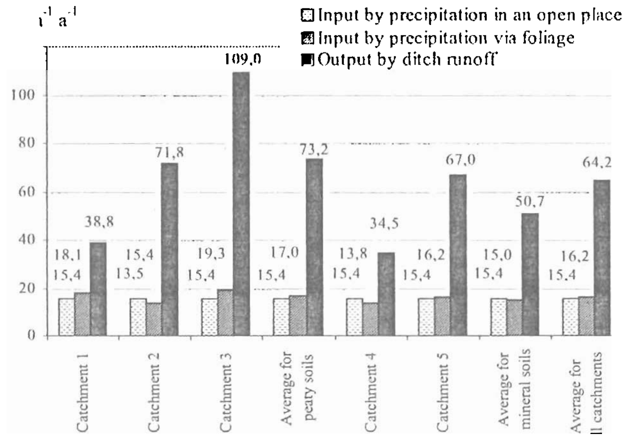

Figure 9. Mg^{2+} balance 01.07.98 – 30.06.99.

Over a year–long period (July 1, 1998 – June 30, 1999) the input of N, K and P ions exceeds the output, whereas the output of Ca^{2+} and Mg^{2+} ions by ditches is several times as much as their input by precipitation. An increased Ca^{2+} and Mg^{2+} output by ditch runoff is believed to prove an inherent peculiarity of the Latvia,s wetland forests, including those of the Vesetnieki experimental area: subsoil water pressure discharge from the upper Devonian dolomite layer considerably contributes to the "assets" of the water balance and the processes of swamping (Zālītis, 1983, in Russian). Ca^{2+} and Mg^{2+} saturated waters partly join the soil groundwater, partly discharge directly into the drainage system, accounting for the alkaline reaction of the ditch runoff (pH > 7.0).

The data on the concentration of different substances dissolved in the soil groundwater is believed to be a fairly good indicator of the variations in the content of different biogenous elements in the soil over time. By comparing the data on the concentration of different biogenous elements in the soil groundwater of the forests on peaty soils soon after the drainage (1996 – 1974), at the moment the stock volume reached ca 100 m^3 / ha, and at present, when the stock volume is 292 m^3 / ha, it is possible to assess the statistical significance of these variations (Fig. 10). Over the past 30 years, only the concentration of N-NO_3^- in the soil groundwater has increased significantly (from 0.1 mg/l to 0.5 mg/l). This holds for the changes in pH (from pH 5.97 to pH 6.72).

Discussion

The results of the present research can be evaluated mainly as a statement of facts. A number of researcher generations have been dealing with the problem of determining the amount and concentration of

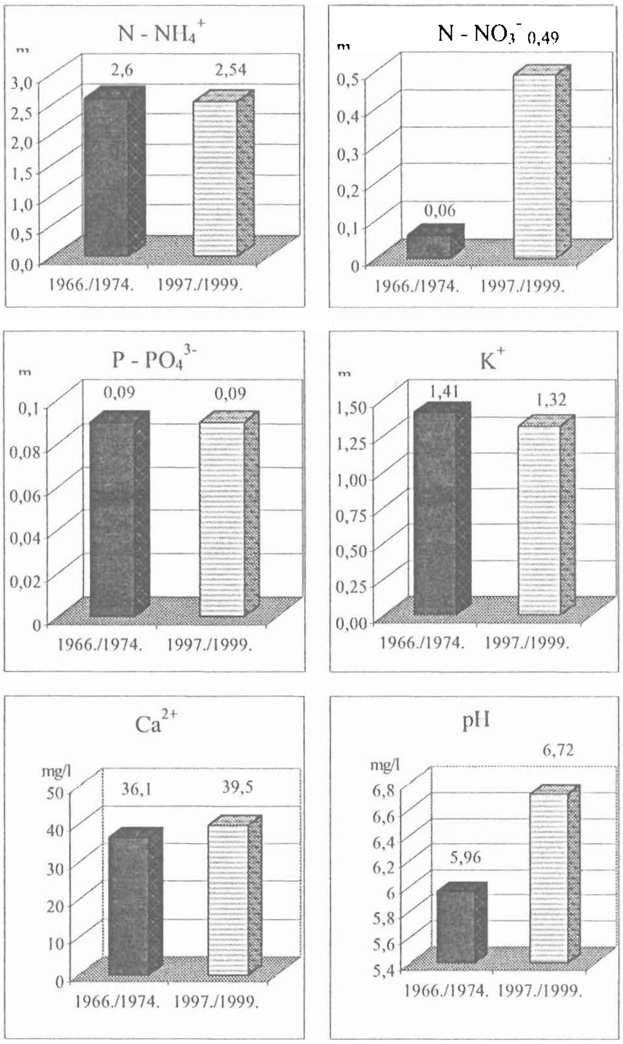

Figure 10. Variations in the concentration of substances analysed and the changes of pH number in groundwater of drained forests on a deep layer of peat.

biogenous elements in farmlands, forest and waters (Odum, 1975, in Russian). However, no description of the biogenous element cycle in woodlands in terms of a comprehensive balance is so far made. Thus, the fixing of biogenous elements (primarily N and P) from the atmosphere is still unknown, the same refers to their entering into different compounds at the microbiological level, and the mechanism of the flow of N– and P– containing organic compounds within a forest phytocenosis (Jonasson, Shawer, 1999).

To increase the comparability of the data obtained by different researchers, it is believed expedient to focus on the problem of data credibility. The results of the given study show the data on biogenous element concentration in forest ecosystem to be highly dispersed over time and also on the particular area, as in the case with the precipitation in the open space, and especially under the forest canopy. No higher precision data on the element concentrations and the input estimation accuracy can be achieved by using larger precipitation collectors and prolonging the period of precipitation water collection. We support the opinion that the data credibility may be increased by reducing the intervals between measurements (Kimmins, 1973).

The reaction of rainwater (average pH 6.5) over the experimental area attests to no pollution of the air by the negative ions of nitrogen and sulphur , as well as by heavy metals; no deterioration of the reaction of water with time: pH 6.0 also thirty years ago (Zālītis, 1983, in Russian).

Absence of significant variations in the concentration of biogenous elements in the soil groundwater during 30 years after drainage prove that the hydrotechnical drainage of woodlands in an environment–friendly fashion is feasible. Our deductions agree with those of similar research on the forests of southern taiga in Russia (Orlov, 1991, in Russian), where no variations either in nutrient availability or pH were detected 5 years after drainage.

There is no agreement between the present data on the increase in N-NH_4^+ concentration in the water along with an increase in the runoff, and those describing the balance of substances for a tract of drained farmland (Zīverts et. al., 1996), where no regularity is found between the volume of runoff and the concentration of nitrogen ions. These facts can most probably be related to an increased concentration of the mentioned ions right after fertilizer application, irrespective of the volume of runoff from the farmland; the amount of substances drained off by water from the farmland in question is 23.6 kg/ha per year (Šķiņķis, 1992), while the same index of the *Vesetnieki* forests is 7.8 kg/ha.

Not only our data but also those of numerous researchers, whom it is not possible to mention here, prove that in the forest ecosystem the nutrient balance over a year or longer period is smoothed out, i.e. the nutrient input does not exceed the output. Such an input / output ratio is a fairly significant precondition for the ecosystem preservation. Over a longer period (during several decades) the input exceeds the output. This results in a gradual increase in the biogenous elements accumulated by the forest ecosystem, thus contributing to the ecological value of drained woodlands. Degraded woodlands, supplanted by high–productivity forest stands, is a sound proof of hydrotechnical drainage as an environment – friendly management practice in forest cultivation.

Conclusions

1. Over 40 years hydrotechnical drainage of wetland forests resulted in an increase in the stock volume from 40 m^3/ha to 292 m^3/ha. Concurrently, the concentration of $N\text{-}NO_3^-$ in the soil groundwater increased from 0.1 mg/l to 0.5 mg/l, pH number has changed from 5.97 to 6.72; variations in the concentration of other elements have no significance.

2. Over a year-long period, the total amount of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ that has reached the soil via precipitation, is higher in an open area, while the total amount of, K^+, Ca^{2+} and Mg^{2+} is higher in the precipitation water that has flown through the forest canopy.

3. The input of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, K^+ in the forest ecosystem by the precipitation exceeds the output of the same substances by ditch runoff. This is true for both forests on a deep layer of peat and those on hydromorphic mineral soils. The output of Ca^{2+} and Mg^{2+} by the ditch runoff is several times higher than the input of the respective ions by the precipitation. It is due to the soil groundwater and ditch runoff, suplemented by the waters of subsoil water pressure discharge from the upper Devonian dolomite layers.

4. The correlation between the $N\text{-}NH_4^+$ concentration (mg/l) in the ditch runoff and the runoff intensity (mm/diurnally) is significantly positive ($r = +0.68$ at $r_{0.05;17} = 0.48$), supposedly due to weakened soil aeration at higher levels of the groundwater table.

References

Bušs K. 1981. Meža ekoloģija un tipoloģija [Forest ecology and typology]. Rīga, 68 lpp. (in Latvian).

Jonasson S., Shawer G. R. 1999. Within – stand nutrient cycling in arctic and boreal wetlands. Ecology. 80., No. 7: 2139–2150.

Kimmins J. P. 1973. Some statistical aspects of sampling troughfall precipitation in nutrient cycling studies in British Columbian coastal forests. Ecology. 54., No. 5: 1008–1019.

Markus R. 1936. Nosusināšanas ietekme priedes un egles pieaugumā purvaugsnēs Latvijā [Drainage impact on the growth of pine and spruce on swampy soils]. Latv. mežu pētn. st. Raksti, 5: 204 lpp. (in Latvian).

Ostwald E. 1878. Über den Einfluss der Entwässerungen versumpfter Orte auf den Baumwuchs. Baltische Woch. – Schr., 13: 16–22. (in German).

Šķiņķis C. 1992. Hidromeliorācijas ietekme uz dabu [Land-reclamation and nature]. Rīga 303 lpp. (in Latvian).

Zālītis P. 1996. Amelioration and ecological diversity of forests in Latvia. Baltic Forestry. Vol. 2., No. 1: 21–26.

Zīverts A., Jauja I., Meža-Eriņš G. 1996. Nosēdtilpju loma biogēnās noteces aizturēšanā nosusināšanas sistēmās [The role of sedimentation basins to prevent the runoff of biogenous substances in the drainage systems]. LLU Raksti 6., Jelgava, 116–125 lpp. (in Latvian).

Залитис П. 1983. Основы рационального лесоосушения в Латвийской ССР [Basics of rational forest drainage in Latvian SSR]. Рига, 232 с. (in Russian).

Одум Ю. 1975. Основы экологии [Fundamentals of ecology]. Москва, 742 с. (in Russian).

Орлов А. Я. 1991. Почвенно – экологические основы лесоводства в Южной Тайге [The pedological and ecological fundamentals of forest management in the southern taiga]. Москва, 104 с. (in Russian).

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ВЛИЯНИЕ ГИДРОТЕХНИЧЕСКОЙ МЕЛИОРАЦИИ НА КРУГОВОРОТ НЕКОТОРЫХ БИОГЕННЫХ ЕЛЕМЕНТОВ В ЛЕСУ

А. Индриксонс, П. Залитис

Резюме

Для успешного решения экономических проблем лесного хозяйства с учетом требований охраны природы, недостаточно изученными до сих пор считались вопросы о влиянии гидротехнической мелиорации как на насыщенность торфяной почвы биогенными элементами, так и на их концентрацию в водоемах. С целью получить обоснованные знания о круговороте некоторых биогенных элементов, важных для жизни леса, в осушенных лесах в 1997 году на стационаре Весетниски возобновлены систематические измерения содержания этих элементов в атмосферных осадках на открытом месте, под пологом леса, в почвенно-грунтовых водах и в стоке воды по осушительным каналам. Полученные данные сопоставлены с результатами измерений тридцатилетней давности на тех же обектах. За это время запас древостоев увеличился в среднем с 100 $м^3$/га на 292 $м^3$/га, но в почвенно-грунтовых водах существенно увеличилось лиш содержание $N\text{-}NO_3^-$ (от 0.1 мг/л до 0.5 мг/л) и изменился pH от 5.97 на 6.72. Содержание остальных биогенных элементов осталось на прежнем уровне. Приток азота, фосфора и калия с атмосферными осадками в течение года превышает вынос этих элементов со стоками воды по осушительными каналами как в лесах на глубоком слое торфа, так и в лесах с гидроморфными минеральными почвами.

Ключевые слова: гидрология леса, лесоосушение, биогенные элементы.