Macro- and microelement concentrations of Finnish timothy in 1974 and 1987

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MÄKELÄ-KURTTO, R., ERVIÖ, R. & SIPPOLA, J. 1993. **Macro- and microelement concentrations of Finnish timothy in 1974 and 1987.** Agric. Sci. Finl. 2: 337-344. (Agric. Res. Centre of Finland, Inst. of Soils and Environment, FIN-31600 Jokioinen, Finland.)

Macro- and microelement concentrations of timothy (*Phleum pratense* L.) in 1974 and 1987 were compared. Timothy samples were collected from the same Finnish fields in 1987 as in 1974 and analyzed for seventeen elements. The biogenic element concentrations of timothy were mostly unchanged or slightly decreased. The decreases were most probably due to differences in the weather conditions between the years and in the stage of development of the plants at the time of sampling. The decrease in timothy Zn was apparently caused by the decrease in soil Zn. In 1987, the mineral nutritive value of timothy as animal feed was nearly the same as in 1974, but lower than the recommendations valid today.

In both years, the concentrations of harmful elements in timothy were low. A drastic decrease in Pb from 1974 to 1987 was due to a remarkable decrease in the Pb emissions from traffic into the atmosphere.

Timothy grown on fine mineral soils was rich in K, Al, Cd, Cu and Ni, while timothy from organic soils was rich in P, Mg, Fe and Mo. The only clear regional difference was in the Pb concentration; it was higher in the south than up north.

Key words: grass, hay, minerals, heavy metals, soil type groups, cultivation zones

Introduction

Plants take up mineral elements mostly by their roots from the soil, but to some extent also by their leaves from the air. Changes in concentrations of both media may cause changes in concentrations of the plants. Soil characteristics are affected by cultivation practices like fertilization, liming, etc., and by atmospheric depositions. The quality of the air is influenced by emissions from natural and anthropogenic sources. Soil factors like texture, acidity and organic matter content influence the uptake of the elements. Weather conditions also regulate the uptake of different elements by the plants. Finally, the element concentrations of the plants are dependent on the plant species, cultivar and plant part in addition to the stage of development. However, elements occurring as structural components tend to vary less than those having specific metabolic functions in the plant.

In 1974, soil and timothy samples were collected from about 2000 sampling sites in different parts of Finland. The samples were analyzed for macro- and microelements. Research results of the soil survey were published by SIPPOLA and TARES (1978) and those of the timothy survey by KÄHÄRI and NISSINEN (1978) and by PAASIKALLIO (1978). In 1987, 1320 of the same fields were resampled; 1320 soil and 403 timothy samples were collected. The chemical characteristics of the soils were studied

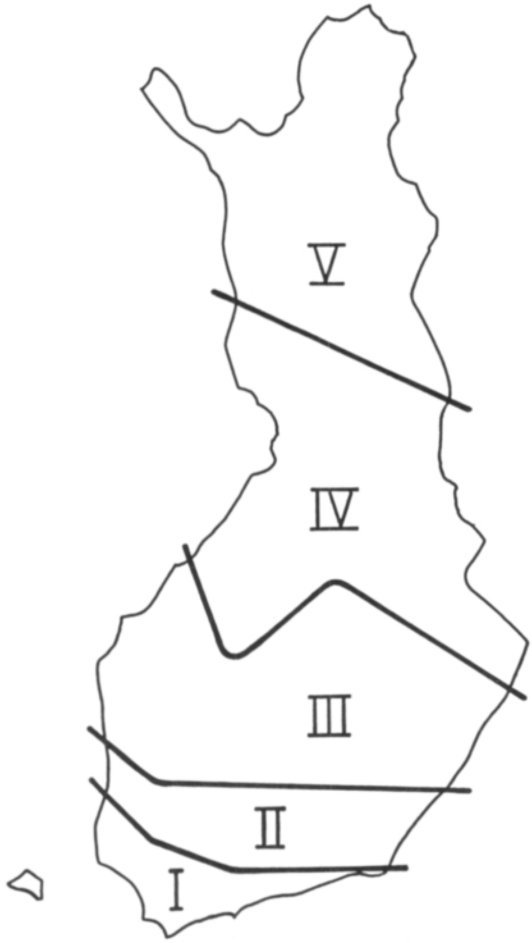

Fig. 1. Cultivation zones (I-V) in Finland.

within the Finnish Acidification Project, 1985-1989. The research results were published by ErvIö et al. (1990).

The aim of this study was to investigate the concentrations of macro- and microelements of the 1987 timothy samples and to compare them with those of 1974. The effects of soil characteristics, air quality and weather conditions were evaluated.

Material and methods

Sampling

In 1987, 407 timothy (*Phleum pratense* L.) samples were collected from five cultivation zones of Finland (Fig. 1); 403 were from the same fields as in 1974. Each plant sample (200-400 g DM) consisted of four subsamples which were taken from the four corners of the 10 x 10 m sampling sites, which were at least 100 m away from the nearest highway and at least 50 m from the nearest electric line. Sampling was done after the spikes of timothy had formed but before flowering. Thus, in southern Finland timothy was sampled about two weeks earlier than in northern Finland.

The weather conditions during the two growing seasons are described in Table 1. It shows the effective temperature and precipitation sums in 1974 and 1987 and their means in 1961-1990 at three Finnish meteorological stations, i.e. Helsinki, Jyväskylä and Oulu. These stations were selected so as to cover nearly the whole sampling area.

Table 1. Effective temperature and precipitation sums in 1974 and 1987 and long-term means in period of 1961-1990.

Meteorological station	Date	1974	1987	Mean 1961-1990
		Effective temperature sum (°C)		
Helsinki	June 30	345	348	469
latitude 60°	July 10	443	450	-
	- " - 15	494	496	634
Jyväskylä	June 30	324	319	408
latitude 62°	July 10	427	415	-
	- " - 15	481	445	562
Oulu	June 30	342	281	346
latitude 65°	July 10	453	373	-
	- " - 15	513	404	505
		Precipitation sum (mm)		
Helsinki	May 1-July 15	110	141	(132)[1)]
Jyväskylä	- " -	129	175	(174)
Oulu	- " -	126	154	(130)

[1)] May 1-July 31

Plant analyses

Before analyses timothy samples were air-dried at 60°C and ground in a hammer mill of pure carbon steel to pass a 2 mm sieve. Mineral element concentrations were expressed on a dry matter (DM) basis.

DM contents of air-dry timothy samples were determined by drying them at 105°C for 4 h. The samples were cooled in a desiccator for 2 h and weighed before ashing.

For determination of calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), aluminium (Al), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb) and zinc (Zn) concentrations, the timothy samples (5.0 g) were dry-ashed at 450°C overnight (Agricultural Research Centre 1986). The ash was moistened with a few drops of water and thereafter dissolved in 10 ml of 3 N HCl in a water bath. The hot solution was filtered into a 50 ml volumetric flask by rinsing. The filter paper and residue were ashed again at 600°C and treated with HF to release the remaining elements in the residue.

The Cd, Co, Mo and Pb concentrations were measured by atomic absorption spectrophotometry (AAS) using a graphite furnace. The concentrations of other elements were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). For the determination of sulphur (S) and boron (B) concentrations, the timothy samples were wet-ashed in concentrated HNO_3, and then measured by ICP-AES.

The methods of plant analyses employed for the timothy samples collected in 1974 have been described by Kähäri and Nissinen (1978) as well as by Paasikallio (1978). The element concentrations of timothy measured at the Agricultural Research Centre in 1974 and 1987 could be considered very comparable due to good and continuous quality control of analytical methods and quality assurance of analytical results.

Statistical methods

The statistical methods used were frequency analysis, t-test and analysis of variance. Statistical calculations were made separately for each cultivation zone (Fig. 1) and each soil type group which were: (A) coarse mineral soils (till, sand and finesand); (B) fine mineral soils (silt and clay); and (C) organic soils (peat, mould and gyttja).

Results and discussion

Changes from 1974 to 1987

Macroelements

The mean concentrations of Ca, K, Mg and P of timothy were lower in 1987 than in 1974 even though the extractable concentrations of the soil elements did not change or they even increased (Erviö et al. 1990). The mean decreases varied between 10-17% (Table 2).

The decreases in Ca and Mg concentrations during the study period most probably resulted from the differences in the weather conditions between the growing seasons and in the stage of development of timothy. In 1987, the effective temperature sums were lower and precipitation sums higher than in 1974 (Table 1), and the plant samples were collected at a slightly earlier and less mature stage of development. According to Keränen (1941), the Ca concentrations in timothy are usually lower in younger plants and increase up to flowering. Similarly, the Mg concentration of the plants generally increases with age (Davies and Lane 1982). Svanberg and Ekman (1946) showed that the Mg concentration of timothy does not increase during two weeks at the time of flowering.

The timothy P and K concentrations decreased by 10% from 1974 to 1987. These are elements, which usually decrease with age of the plants (Keränen 1941, Salo et al. 1990).

The mean S concentration of timothy in 1987 was about the same as that reported by Sillanpää and Jansson (1991), whereas, the mean S concentration of timothy grown on acid sulphate soils (Palko 1986) was clearly lower than that reported in the present study.

Microelements

The mean boron concentration of timothy did not change from 1974 to 1987 (Table 2), although B was added each year into the soils as a component of all NPK fertilizers since 1972 and soluble B in the soils significantly increased between 1974 and 1987 (Erviö et al. 1990). Younger plants usually

Table 2. Means and ranges of mineral element concentrations of timothy samples (n = 403) in 1987 and mean differences from 1974. Concentrations expressed on a dry matter (DM) basis.

Element, concentration		Mean 1987	Range 1987	Mean difference from 1974	
Ca	g kg^{-1} DM	2.10	(1.03-4.64)	-0.4***	-16 %
K	- " -	21.6	(8.7-41.1)	-2.3***	-10 %
Mg	- " -	1.06	(0.46-2.71)	-0.21***	-17 %
P	- " -	2.65	(1.35-4.56)	-0.29***	-10 %
S	- " -	1.37	(0.76-2.85)	-	-
Al	mg kg^{-1} DM	12.6[1)]	(1.4-218.9)	+1.4 NS	+11 %
B	- " -	4.7[1)]	(1.22-21.18)	-0.03 NS	-1 %
Cd	- " -	0.019[2)]	(0.002-0.057)	+0.002 NS	+12 %
Co	- " -	0.054[3)]	(0.001-0.622)	-0.011 NS	-17 %
Cr	- " -	0.40[3)]	(0.19-5.63)	+0.16***	+67 %
Cu	- " -	3.87	(0.81-11.21)	-0.37***	-9 %
Fe	- " -	36.4[1)]	(10.9-163.1)	-6.4***	-15 %
Mn	- " -	52.9	(11.8-181.3)	-14.4***	-21 %
Mo	- " -	0.49[1)]	(0.01-14.01)	+0.03 NS	+7 %
Ni	- " -	0.51[3)]	(0.01-3.72)	+0.13 NS	+34 %
Pb	- " -	0.17[3)]	(0.004-4.44)	-0.14*	-45 %
Zn	- " -	24.8	(11.0-83.5)	-7.0***	-22 %

[1)] n = 402
[2)] n = 84
[3)] n = 45

t-test: * = (P > 0.05)
*** = (P > 0.001)
NS = not significant

contain lower concentrations of B (SMITH 1962). Most probably that is the reason for plant B not being changed.

Similarly, less mature plants have lower Fe and Mn concentrations (SMITH 1962). Due to age, timothy Fe and Mn decreased in spite of the increase in soil Fe and no change in soil Mn from 1974 to 1987 (ERVIÖ et al. 1990). The mean concentrations of Co and Mo were about the same in 1987 and 1974, although the concentrations of these elements increased in soils (ERVIÖ et al. 1990).

From 1974 to 1987, the mean Cu, Mn and Zn concentrations of timothy decreased by 9, 21 and 22%, respectively. During the study period, soil extractable Cu increased by 32%, Mn did not change, and Zn decreased by 22%. The decrease in soil Zn apparently decreased the concentration of Zn in timothy, too. Moreover, the higher pH-value of the soils in 1987 (ERVIÖ et al. 1990) may have reduced the availability of these micronutrients to plants.

Harmful elements

Between 1974 and 1987, there were no changes in the mean Al and Ni concentrations of timothy samples (Table 2) or soil samples (ERVIÖ et al. 1990). Particularly high Al concentrations in timothy were reported by PALKO (1986) on Finnish acid sulphate soils which were few in this study.

The mean Cd concentration of timothy in 1987 did not differ significantly from that in 1974, even though the concentrations of soluble Cd in soils increased by 30% (ERVIÖ et al. 1990). On the other hand, Cd depositions have gradually decreased in northern Europe during the last decades (Nordic Council of Ministers 1992). The major part of plant Cd originates usually from the soil, but 20-60% of herbage Cd can be directly deposited from the air (HOVMAND et al. 1983). Atmospheric Cd may be absorbed into the plant and transported throughout it. Furthermore, soil pH that strongly regulates the uptake of Cd by the plants (ANDERSSON and

NILSSON 1974), was higher in 1987 than in 1974 (ERVIÖ et al. 1990).

The mean increase in the timothy Cr from 1974 to 1987 was 67%, whereas extractable soil Cr increased by 17%. In general, most of the plant Cr originates from the air (MOSBAEK and TJELL 1985).

A drastic decrease in the mean Pb concentrations of timothy was between the two years. In 1987, the concentration was 45% lower than in 1974. The decrease was due to the remarkable decline in domestic emissions of Pb into the air from traffic between 1974 and 1987. In the 1970's, the total emissions of Pb from automobiles in Finland were about 1000 tons per year (Finnish Ministry of Internal Affairs 1981). The Pb concentration of petrol was gradually reduced in the 1980's and Pb-free fuel has been available since 1985 (Finnish Ministry of Environment 1989).

In 1987, Pb emissions from traffic in Finland amounted to 200-300 tons. Still, automobile traffic was the principal source of Pb emissions into the air (VORNAMO 1984). Depositions are usually responsible for more than 90% of plant Pb (MOSBAEK at al. 1989). Thus, a notable decrease in the Pb emissions must have influenced the Pb concentrations of timothy. A positive effect of diminished Pb emissions on the Pb concentration of the plants was observed also by MÄKELÄ-KURTTO and TARES (1987); the mean Pb concentration of one-year old pine needles in the Helsinki area decreased to one third from 1970 to 1986.

Differences between soil type groups

Timothy plants grown on coarse mineral soils contained less elements than the plants grown on other soil types, on average (Table 3). Zn was an exception; the highest concentration was observed in timothy grown on coarse mineral soils.

The lowest mean Ca and B concentrations and the highest K, Cd and Cu concentrations were in the samples collected from fine mineral soils. Similarly, according to SIPPOLA and MÄKELÄ-KURTTO (1986), the mean Cd concentration of timothy grown on clay soil was higher than that of timothy grown on organic or coarse mineral soils. Al and Ni concentrations of timothy from fine mineral soils were nearly twice as high as the respective values in timothy from other soils.

Table 3. Means of macro- and microelement concentrations of timothy by soil type group (A = coarse mineral soils; B = fine mineral soils; C = organic soils) in 1987. Concentrations expressed on a dry matter (DM) basis.

Year		1987	
Soil type group	A	B	C
No of samples	232	75	100
Ca g kg^{-1} DM	2.15^b	1.90^a	2.13^b
K - " -	21.8^b	23.7^c	19.7^a
Mg - " -	1.02^a	1.03^a	1.17^b
P - " -	2.58^a	2.62^a	2.84^b
S - " -	1.36	1.34	1.40
Al mg kg^{-1}DM	11.0^a	20.2^b	10.8^a
B - " -	4.83^b	4.01^a	5.08^b
Cd - " -	0.020^{ab}	0.021^b	0.017^a
Co - " -	0.042	0.062	0.057
Cr - " -	0.42	0.50	0.41
Cu - " -	3.76^a	4.46^b	3.69^a
Fe - " -	34.0^a	39.2^{ab}	40.3^b
Mn - " -	51.0	57.8	54.3
Mo - " -	0.40^a	0.35^a	0.82^b
Ni - " -	0.36^a	0.80^b	0.40^a
Pb - " -	0.12	0.16	0.19
Zn - " -	26.3^b	22.2^a	23.5^a

Means in each row followed by a common index letter do not differ at P = 0.05 within the year.

The plants grown on organic soils had the highest mean P, Mg, Fe and Mo values and the lowest mean Cd value. The Mo concentration of timothy grown on organic soil was about two times that grown on other soils. This is in accordance with an observation of PAASIKALLIO (1978). As to differences between the years by soil type group, the decreases in the concentrations of macroelements in timothy from 1974 (KÄHÄRI and NISSINEN 1978) to 1987 were the most notable on organic soils.

Differences by cultivation zone

Clear differences in the mineral element concentrations of timothy between the cultivation zones were very few (Table 4). The Pb concentrations of timothy, like those of cultivated soils (ERVIÖ et al. 1990), clearly diminished from the south to the

Table 4. Means of macro- and microelement concentrations of timothy by plant cultivation zone in 1987. Concentrations expressed on a dry matter (DM) basis.

Year		1987			
Cultivation zone	I	II	III	IV	V
No of samples	6	74	195	97	35
Ca $g\ kg^{-1}$ DM	2.06	2.06	2.13	2.01	2.24
K - " -	23.0	22.2	21.2	21.0	24.6
Mg - " -	1.11	0.96	1.02	1.18	1.18
P - " -	2.62^{a}	2.60^{a}	2.60^{a}	2.64^{a}	3.10^{b}
S - " -	1.56	1.34	1.36	1.36	1.39
Al $mg\ kg^{-1}$ DM	19.2	17.9	12.0	11.5	7.8
B - " -	4.53^{a}	3.77^{a}	4.44^{a}	5.23^{a}	7.18^{b}
Cd - " -	0.022	0.020	0.019	0.018	0.023
Co - " -	0.034	0.051	0.042	0.066	0.048
Cr - " -	0.41	0.46	0.42	0.44	0.44
Cu - " -	4.82	4.01	3.76	3.83	4.11
Fe - " -	42.7	37.1	35.3	37.5	38.6
Mn - " -	59.3	58.5	50.8	50.8	59.5
Mo - " -	0.26	0.69	0.53	0.36	0.24
Ni - " -	0.71	0.63	0.45	0.40	0.56
Pb - " -	0.29^{b}	0.24^{ab}	0.12^{ab}	0.14^{ab}	0.06^{a}
Zn - " -	25.8^{a}	24.7^{a}	23.8^{a}	24.3^{a}	32.4^{b}

Means in each row followed by a common index letter do not differ at P = 0.05 within the year.

north, because traffic density and Pb emissions diminished to the same direction, too. Furthermore, the decrease in the timothy Pb from 1974 to 1987 was the most significant in southern Finland (Erviö 1989) due to the most remarkable decrease in the Pb emissions there.

The mean P, B and Zn concentrations were the highest in timothy from the northernmost cultivation zone (V). This might be due to the differences in the soil types. In this study, dominating soil types in southern Finland were fine mineral soils and in northern Finland coarse mineral soils. In addition to this, the proportion of organic soils was greater in the north than in the south (Erviö et al. 1990).

Nutritive value of timothy

The nutritive value of timothy is of importance, since timothy is one of the main forage plants cultivated for animal feeds in Finland. Optimal element concentrations of the grass for cattle feeding are: Ca 4.0-4.5 g, K 20-30 g, Mg 2 g, Fe 100 mg, Cu 10 mg, Mn 40 mg, Mo 0.3 mg and Co 0.1 mg kg^{-1} DM (Salo et al. 1990, Association of Rural Advisory Centres 1992). The optimal range of K concentrations is rather narrow in grass, because concentrations lower than 20 g kg^{-1} DM indicate K deficiency in the plants and those higher than 30 g kg^{-1} DM are excessive for animals (Kasvata nurmiviljelyn tulosta ... 1993). Considering the stage of development of the plants, the mineral element concentrations of timothy obtained here were about the same as those reported by Lakanen (1969) and by Kähäri and Nissinen (1978), but lower than the values recommended today.

Conclusions

The differences in the mineral element concentrations of timothy between 1974 and 1987 were mainly due to the weather conditions and the stage of development of the plants. However, some supportive measures, e.g. Zn fertilization, may be needed to optimize the nutritive value of grass for animal feeding. The purity of grass can be enhanced by reducing emissions of heavy metals into the atmosphere.

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Manuscript received January 1993

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SELOSTUS

Suomalaisen timotein alkuainepitoisuudet vuosina 1974 ja 1987

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Maatalouden tutkimuskeskus

Koko Suomen alueelta vuonna 1987 tähkimisvaiheessa kerätyistä timoteinäytteistä analysoitiin 17 alkuainetta, joiden pitoisuuksia verrattiin 13 vuotta aikaisemmin samoilta paikoilta kerättyjen näytteiden vastaaviin pitoisuuksiin. Myös maalajien ja viljelyvyöhykkeiden merkitystä timotein alkuainekoostumukseen tarkasteltiin.

Timoteinäytteiden keskimääräiset kalsium-, kalium-, magnesium-, fosfori-, kupari-, mangaani-, rauta-, lyijy- ja sinkkipitoisuudet olivat vuonna 1987 pienempiä kuin vuonna 1974. Alumiinin, boorin, kadmiumin, koboltin, molybdeenin ja nikkelin arvot eivät poikenneet kyseisinä vuosina. Timotein kromipitoisuus oli vuonna 1987 suurempi kuin vuonna 1974.

Todetut erot timotein alkuainepitoisuuksissa johtunevat pääasiassa eroista kasvukausien sääoloissa ja timotein kehitysasteessa. Timotein sinkkipitoisuuden pienenemisen syy oli viljelymaiden helppoliukoisen sinkin väheneminen. Kasvien lyijypitoisuuden pieneneminen oli seurausta liikenteen lyijypäästöjen oleellisesta vähenemisestä tutkimusaikavälillä.

Eloperäisiltä mailta kerätyt timoteinäytteet sisälsivät enemmän magnesiumia, fosforia, molybdeenia ja rautaa, mutta vähemmän kadmiumia kuin kivennäismailta kerätyt näytteet. Pohjoisimmalla viljelyvyöhykkeellä kasvaneesta timoteista todettiin alhaisimmat lyijypitoisuudet.