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Influence of sodium and potassium fertilization on the sodium concentration of timothy

Tommi Peltovuori
Department of Applied Chemistry and Microbiology, PO Box 27, FIN-00014 University of Helsinki, Finland,
e-mail: tommi.peltovuori@helsinki.fi

Markku Yli-Halla
Department of Applied Chemistry and Microbiology, FIN-00014 University of Helsinki, Finland. Current address:
Institute of Resource Management, Agricultural Research Centre of Finland, FIN-31600 Jokioinen, Finland

Sodium (Na) concentration of forage crops grown in Finland, particularly that of timothy, is much lower than is recommended in the feed of cattle. A pot experiment was carried out on clay, loam and organogenic soils to find out the effect of Na application (0, 200 or 400 mg dm^{-3} of soil, one application) on the concentration of Na, K, Ca and Mg of timothy and the effect of K fertilization (0, 100 and 200 mg dm^{-3} for each three harvests) on the efficiency of Na application. Added Na elevated the Na concentration in all harvests on all soils. The magnitude of the effect (organogenic soil$\gtrsim$loam>clay) was opposite to the K supplying power of the soil. Potassium fertilization suppressed the effect of Na application substantially and Na concentration was elevated remarkably only when the K concentration of the plants fell to or below the deficiency level (approximately 15 g kg^{-1}). According to a cation exchange experiment, nearly all added Na remained in the soil solution. Still, the apparent utilization of added Na remained below 4% on all soils, demonstrating the natrophobic nature of timothy. Sodium fertilization of timothy seems to be an ineffective way of increasing the Na content of forage at least on soils of a good K status or when applied with ample K fertilization.

Key words: calcium, cation exchange isotherms, magnesium, mineral composition of forage, pot experiment, selectivity in cation exchange

Introduction

Sodium (Na) can substitute for potassium (K) in the biophysical functions of K in most plants, e.g. in regulating osmotic pressure in vacuoles, and to a limited extent in biochemical functions, e.g. in activation of enzymes. However, the ability of Na to substitute for K varies greatly between plant species (Flowers and Läuchli 1983). Most agronomically significant species like timothy, rye, corn and soybean are natrophobic. In these species Na cannot effectively substitute for K and the Na concentration of plants tends to be

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low. The average Na concentration of timothy in Finland (mean 0.047 g kg^{-1}, Kähäri and Nissinen 1978) is of the same order as that of the micronutrients Fe, Mn and Zn, while in other grasses like cocksfoot (0.3 g kg^{-1}, Rinne et al. 1974), and particularly in ryegrass (0.8 g kg^{-1}, Jansson 1986), the Na concentration tends to be higher.

The Na concentration of cereals is relatively unimportant but that of pasture species affects the quality of fodder used for animal production. Sodium is an essential mineral element for animals, and forage should contain Na 1.8–2 g kg^{-1} of dry matter to supply milking cows with sufficient Na (NJF 1975, Smith and Middleton 1978, Horn 1988). Thus, there is a big difference between the requirement of cattle and the supply of Na from farm-produced fodder in Finland, and it has to be compensated with mineral supplements. Another imbalance of mineral elements in fodder is brought about by heavy K fertilization of leys leading to excessive K concentration and lower than optimum concentration of other cations, especially magnesium (Mg), in herbage (Smith and Middleton 1978, Leigh et al. 1988). The equivalent ratio K/(Ca+Mg) has been used as a criterion for forage grass quality; values below 2.2 are desired (Ettala and Kossila 1979). Substitution of Na for K in plants has been shown to increase their Mg concentration (Nowakowski et al. 1974, Smith 1974, Smith et al. 1980, Mundy 1983). Sodium application can thus improve the feeding quality of herbage by increasing the concentration of Na and Mg and possibly by lowering the concentration of K. Elevated Na concentration of herbage may also increase the intake of fodder by cows (Horn 1988, Chiy et al. 1993), resulting in an increase in liveweight gain and in milk production (Chiy et al. 1993).

The purpose of this study was to examine whether the Na concentration of timothy can be elevated by Na application and to find out the effects of Na application on the uptake of other cations on three different soils. The effect of K application on the efficiency of Na fertilization was also studied. The natrophobic nature of timothy and its poor response to added Na is evident from the literature. Nevertheless, it was selected as the test crop because, owing to its winter hardiness, it is by far the most common pasture species in Finland. The fate of added Na in soil was also investigated by determining cation exchange isotherms for the cation exchange pairs Na/K and Na/Ca.

Material and Methods

The effect of Na on the growth and chemical composition of timothy was studied in a pot experiment. The experimental soils (silty clay, loam and organogenic soil, Table 1) were taken from plough layers of cultivated fields in Southern Finland. In the text, the silty clay will be referred to as clay. The high concentrations of Ca and Mg and the relatively high pH of the organogenic soil are probably attributable to liming.

The soils were air-dried and ground to pass a 10-mm sieve. For chemical analyses, part of the soil was ground further to pass a 2-mm or a 0.6-mm sieve (C analysis). The carbon concentration was determined using a LECO CHN-900 analyser. The particle size distribution was determined by a pipette method. The pH was determined in a 0.01 M $CaCl_2$ suspension at the

Table 1. Properties of the experimental soils.

	Clay	Loam	Organogenic soil
Particle size distribution, %			
<0.002 mm	44.1	8.0	29.9
0.002–0.02 mm	24.5	19.4	39.4
0.02 mm <	31.5	72.6	30.7
Organic C, %	3.9	2.8	26.6
Soil pH (0.01 M $CaCl_2$)	5.9	6.3	5.8
Exchangeable cations, mg dm^{-3}			
Na	14.5	7.7	9.3
K	283	134	87
Ca	2207	1520	4530
Mg	196	81	225
Bulk density, g cm^{-3}	0.77	0.90	0.34

solution-to-soil ratio of 2.5:1 (v/v). The electrical conductivity of the soil was determined in a water suspension at the solution-to-soil ratio of 2.5:1. Exchangeable cations were extracted with four successive portions of 1 M ammonium acetate, pH 7.0 (Thomas 1982). The soil bulk density was determined for air-dry soil compressed as in the experimental pots.

Kick-Brauckmann pots with 7 dm^3 of soil were used in the pot experiment. A small portion of soil (0.25 dm^3) was taken from each pot to cover the seed and the rest was fertilized. The treatments were:

Sodium as $Na_2SO_4 \cdot 10H_2O$:		Potassium as KCl:	
Abbreviation:	mg dm^{-3}	Abbreviation:	mg dm^{-3}
Na_0	0	K_0	0
Na_1	200	K_1	100
Na_2	400	K_2	200

All the nine combinations were made as 5 replicates for each soil. The pots were fertilized also with other elements as analytical grade chemicals at the following rates (mg dm^{-3}): N as NH_4NO_3 (150), P as $Ca(H_2PO_4)_2 \cdot H_2O$ (150), Mg as $MgSO_4 \cdot 7H_2O$ (80), S in sulfates of Mg, Cu, Mn, Fe and Zn (at least 112), Cu as $CuSO_4 \cdot 5H_2O$ (4), Mn as $MnSO_4 \cdot H_2O$ (4), Fe as $FeSO_4 \cdot 7H_2O$ (2), Zn as $ZnSO_4 \cdot 7H_2O$ (3) and B as H_3BO_3 (2). The seed of timothy (300 mg *Phleum pratense* L. cv. Tuukka) was sown on the fertilized soil and covered with unfertilized soil. Three crops of timothy were harvested. The second and the third crop were fertilized with solutions of N and K at the same rates as at the beginning of the experiment. Sodium was applied only at the beginning. The plants were grown outdoors under a glass roof from May to September and watered with deionized water. The first crop was cut 59 days after planting, the second and the third one after 33 days' growth. The plant material was dried at 65°C and analyzed for Ca, Mg, Na and K according to a dry combustion method by Helrich (1990). Potassium and Na were analyzed by flame photometry, Ca and Mg by atomic absorption spectroscopy. A known sample was included in every analysis series. The coefficients of variation (23 observations) for the analysis of the sample were: Na 17.0%, K 3.6%, Ca 2.9% and Mg 1.1%.

Exchange isotherms were determined for Na/Ca and Na/K exchange on the three soils by a modified method of Levy et al. (1988). Isotherms were determined using 5 g of soil (2 g of organogenic soil) in duplicates. The soil samples were first equilibrated with 25 ml of a mixture of solutions of NaCl and $CaCl_2$ or NaCl and KCl. Seven different cation equivalent ratios (0, 15, 30, 50, 70, 85 or 100 % of Na) were used for both isotherms, and the chloride concentration of the first equilibration solution was 0.5 mol l^{-1}. The suspensions were shaken for 20 min, centrifuged, and the supernatant solution was discarded. This was repeated three times, followed by three similar steps using 50 ml of 0.01 M solutions while maintaining the original Na/Ca or Na/K ratios. The last 0.01 M solutions were filtered through Schleicher & Schüll 589^3 (blue ribbon) filter paper and used to determine Na and K by flame photometry and Ca by atomic absorption spectroscopy. The amount of equilibration solution remaining in the soil samples after equilibration was determined by weighing the centrifuge tubes containing the soil and the solution. Thereafter the exchangeable cations adsorbed on the soil samples were determined by three repeated extractions with 30 ml of 1 M ammonium acetate (20 min shaking, centrifuging and filtering through Schleicher & Schüll 589^3 filter paper). The extracted cations were determined as above. The amount of cations held in the soil by the remaining equilibration solution was deducted from these results.

Results

The dry matter yields were not affected by Na treatments. On the organogenic soil, K fertilization elevated the yields of the second and third harvest by 10 and 51%, respectively ($p<0.001$)

Table 2. Dry matter yields (g pot^{-1}) at the three levels of K application. Treatments: K_0=0 mg dm^{-3}, K_1=3x100 mg dm^{-3}, K_2=3x200 mg dm^{-3}.

	Clay	Loam	Organogenic soil	
Harvest	All K levels	All K levels	K_0	K_1 and K_2
I	15.4	16.5	23.2	23.4
II	31.5	30.0	30.0	32.9
III	24.2	23.8	18.2	27.4
Sum	71.1	70.3	71.4	83.7

(Table 2). Yet, there were no visible K deficiency symptoms in any treatment of the experiment.

Without Na and K application (Na_0K_0), the average Na concentration of timothy (Table 3) was 0.24 g kg^{-1} (range 0.17–0.30 g kg^{-1}), excluding the plants grown on the clay in the first harvest that had a Na concentration (0.57 g kg^{-1}) deviating from the other corresponding results. When no Na was applied, K application seemed to elevate the Na concentration but the effect was not statistically significant.

Application of Na increased the Na concentration of timothy on all soils and in all harvests ($p<<0.001$). The effect was greater for the loam and the organogenic soil than for the clay. The highest Na concentrations of timothy were reached without K and with the highest rate of Na (Na_2K_0) in the third harvest: 6.9 g kg^{-1} on the loam and 5.6 g kg^{-1} on the organogenic soil.

Sodium was much weaker than Ca or K in competition for cation exchange sites (Fig. 1). In Na/K exchange, Na was least efficient competitor for clay and somewhat more efficient for the two lighter soils. In equimolar equilibrium solution (Na/K), Na occupied 24, 33 and 38% of the exchange sites on clay, loam and organogenic soils, respectively. Sodium was even a weaker competitor for exchange sites with Ca than with K. In an equilibrium solution containing 50% of both Na and Ca (expressed in mmol of charge dm^{-3}) there was only 5, 4.5 and less

Table 3. Sodium and potassium concentrations of timothy in the pot experiment (g kg^{-1} dry matter). Treatments: Na_1=200 mg dm^{-3}, Na_2=400 mg dm^{-3}, K_1=3x100 mg dm^{-3}, K_2=3x200 mg dm^{-3}.

			Clay			Loam			Organogenic soil		
	Harvest		K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Na	I	Na_0	0.6^{a}	0.5^{a}	0.7^{ab}	0.3^{a}	0.4^{ab}	0.5^{ab}	0.2^{a}	0.4^{ab}	0.5^{abc}
		Na_1	0.7^{ab}	0.8^{ab}	1.0^{bc}	1.1^{c}	1.1^{c}	1.0^{bc}	1.5^{e}	0.6^{bc}	0.6^{bc}
		Na_2	1.7^{d}	1.6^{d}	1.3^{cd}	2.3^{d}	1.9^{d}	2.0^{d}	2.2^{f}	1.1^{d}	0.8^{c}
	II	Na_0	0.2^{a}	0.6^{ab}	1.0^{bcd}	0.3^{a}	0.5^{ab}	0.5^{ab}	0.3^{a}	0.4^{ab}	0.5^{ab}
		Na_1	0.6^{ab}	0.7^{bc}	1.0^{bcd}	1.5^{cd}	1.0^{bcd}	0.9^{abc}	1.8^{d}	0.6^{b}	0.5^{ab}
		Na_2	1.2^{cd}	1.2^{d}	1.0^{bcd}	3.5^{e}	1.5^{cd}	1.6^{d}	2.8^{e}	1.1^{c}	0.7^{b}
	III	Na_0	0.3^{a}	0.4^{a}	0.5^{a}	0.2^{a}	0.4^{a}	0.6^{a}	0.2^{a}	0.4^{a}	0.5^{a}
		Na_1	1.1^{bc}	0.7^{ab}	0.6^{ab}	3.2^{c}	1.2^{ab}	0.8^{a}	4.2^{c}	0.7^{a}	0.6^{a}
		Na_2	2.6^{d}	1.6^{c}	1.2^{bc}	6.9^{d}	2.6^{bc}	2.4^{bc}	5.6^{d}	1.5^{b}	0.7^{a}
K	I	Na_0	45^{a}	48^{ab}	50^{ab}	31^{a}	43^{c}	48^{cde}	20^{a}	36^{c}	47^{e}
		Na_1	45^{a}	47^{a}	49^{ab}	36^{ab}	45^{cde}	49^{e}	25^{b}	40^{d}	50^{f}
		Na_2	45^{a}	48^{ab}	53^{b}	37^{b}	44^{cd}	49^{de}	26^{b}	38^{cd}	50^{f}
	II	Na_0	31^{a}	42^{b}	45^{b}	13^{a}	34^{c}	41^{d}	10^{a}	26^{b}	40^{c}
		Na_1	32^{a}	43^{b}	44^{b}	17^{b}	35^{c}	41^{d}	11^{a}	29^{b}	42^{c}
		Na_2	33^{a}	42^{b}	45^{b}	19^{b}	34^{c}	45^{e}	10^{a}	27^{b}	42^{c}
	III	Na_0	21^{a}	42^{c}	50^{e}	12^{a}	35^{b}	47^{c}	9^{a}	31^{b}	46^{c}
		Na_1	23^{ab}	45^{d}	48^{e}	13^{a}	37^{b}	47^{c}	9^{a}	32^{b}	48^{c}
		Na_2	24^{b}	42^{c}	49^{e}	14^{a}	36^{b}	46^{c}	8^{a}	31^{b}	46^{c}

Each soil and harvest was tested separately. Means with same superscripts do not differ at $p = 0.05$.

than 3% of exchange sites occupied by Na on clay, loam and organogenic soils, respectively.

Application of K drastically depressed the effect of Na fertilization ($p<0.001$) even though added K was more likely to be bound on the cation exchange sites than Na. In the Na/K exchange, K was least efficient competitor on the organogenic soil, and the effect of K was strongest on this soil; K_2 application decreased the Na concentration of timothy at the Na_2 level in the third harvest to one-eighth of that obtained without K application (Table 3). When plants were fertilized with K, the targeted Na concentration of 2 g kg^{-1} was reached only with the higher Na level in the third harvest on the loam. The sodium concentration of timothy increased most effectively when the K concentration of the plants decreased to or below 15 g kg^{-1} (Fig. 2). These concentrations, suggesting K deficiency, occurred in plants grown without K application in the second and third harvest on the organogenic soil and in the third harvest on the loam.

Application of Na did not decrease the concentration of K in timothy at any K level. Figure 3 demonstrates the abundance of K compared to other cations in the plants fertilized with the same amounts (mg dm^{-3}) of Na and K. When expressed in mol dm^{-3}, the plants received more Na than K. Despite the similar amounts added as fertilizer, the first harvest of timothy grown on mineral soils took 50 times and timothy grown on the organogenic soil 80 times more K than Na. A tenfold increase in Na concentration from the Na_0 level with an equivalent decrease in K concentration would theoretically lower the K concentration by only about 4 g kg^{-1} at the most. Not even this effect seems to be feasible.

Sodium application decreased the Ca concentration of timothy on all soils and for all harvests ($p<0.001$). The mean Ca concentrations were 8.5, 7.2 and 6.6 g kg^{-1} in the treatments Na_0, Na_1 and Na_2, respectively. In the third harvest on the organogenic soil, the Ca concentration of timothy was as much as 35% lower in the Na_2K_0 (10.7 g kg^{-1}) than in the Na_0K_0 (16.5 g kg^{-1}) treatment. Sodium application did not influence the Mg concentrations which, owing to Mg fertilization, were rather high in the experiment. Potassium application strongly lowered the Mg concentration of timothy ($p<<0.001$). The average Mg concentration was 4.6, 3.1 and 2.6 g kg^{-1} in the treatments K_0, K_1 and K_2, respectively.

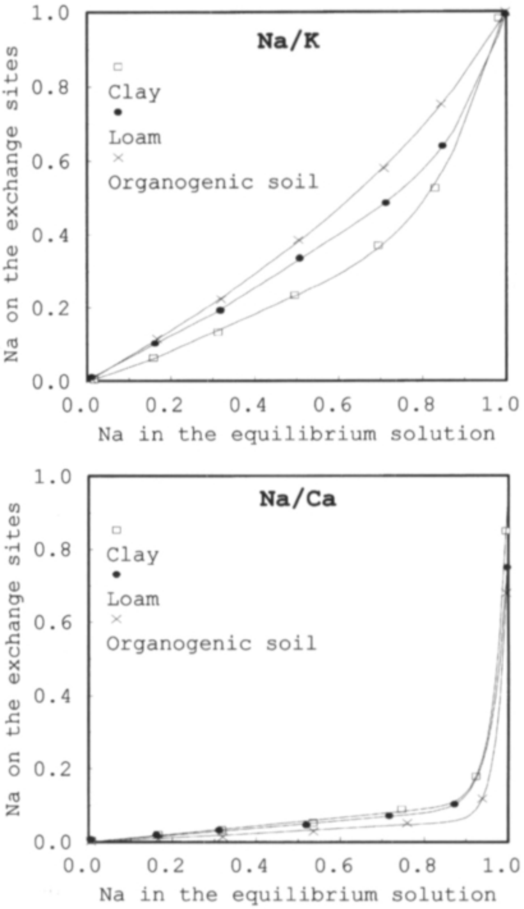

Fig. 1. Cation exchange isotherms for the cation pairs Na/K and Na/Ca. Sodium on the exchange sites and in the equilibrium solution expressed as a fraction of total positive charge.

One of the aims of Na fertilization has been to decrease the excessive concentration of K in herbage and thus to decrease the K/(Ca+Mg) ratio of fodder. In the present study, Na fertilization, on the contrary, increased the ratio ($p<0.001$) because it decreased the Ca concentration but did not affect the K and Mg concen-

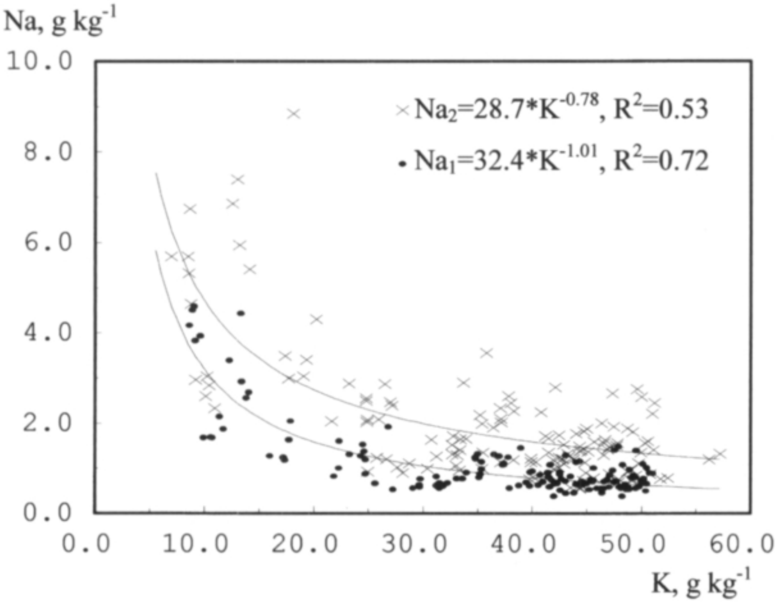

Fig. 2. Relationship of the concentrations of Na and K of timothy fertilized with two Na levels (Na_1 = 200 mg dm^{-3}, Na_2 = 400 mg dm^{-3}).

trations (Table 4). However, the K/(Ca+Mg) ratios remained below 2.5 in all treatments, and the unfavourable effect of Na diminished towards the end of the experiment. Without K application (K_0) the K/(Ca+Mg) ratios decreased to very low values in the third harvest (range 0.2–0.8). Potassium had a strong enhancing effect on the ratio ($p << 0.001$) throughout the experiment. Sodium fertilization lowered the K/Na ratios in the plants ($p << 0.001$) which is considered to improve the quality of fodder.

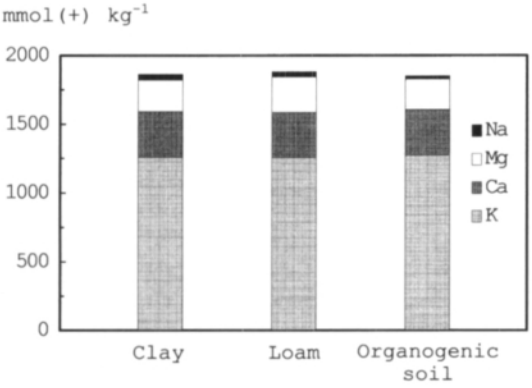

Fig. 3. Na, K, Ca and Mg concentrations of timothy (mmol of charge kg^{-1}) in the first harvest. The plants received similar Na and K fertilization (200 mg dm^{-3}, treatment Na_1K_2).

In the Na_0K_0 pots, 22–34% of the native exchangeable Na was taken up by plants while in the Na_0K_2 pots, 52–71% was taken up. However, the reserves of exchangeable Na were not depleted during the experiment in clay while there was a consistent decrease in the organogenic soil and inconsistent changes in the loam (Table 5). Applied Na elevated the concentration of exchangeable Na in the soil to very high levels. At the end of the pot experiment, Na extracted from the soils of the highest Na treatment represented 11, 14 and 6% of all extracted cations (mol of charge dm^{-3}) in clay, loam and organogenic soils, respectively. The heavy fertilization also elevated the electrical conductivities of the soils. The maximum values at the end of the experiment, measured in the Na_2K_2 pots, were 0.8, 0.6 and 1.0 dS m^{-1} in clay, loam and organogenic soils, respectively.

In pots fertilized with K, the apparent utilization of added Na was less than 4% on all soils and at the K_2 level it remained below 0.8% for the clay and the organogenic soil. At the K_0 level, the utilization of Na was somewhat higher

Table 4. K/(Ca+Mg) ratios (mol of charge kg^{-1}) of timothy in the pot experiment. Treatments: Na_1=200 mg dm^{-3}, Na_2=400 mg dm^{-3}, K_1=3x100 mg dm^{-3}, K_2=3x200 mg dm^{-3}.

		Clay			Loam			Organogenic soil		
Harvest		K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
I	Na_0	1.8^{a}	2.0^{b}	2.1^{bc}	1.1^{a}	1.6^{b}	1.9^{c}	0.6^{a}	1.4^{c}	2.1^{e}
	Na_1	2.1^{bcd}	2.2^{cd}	2.3^{cde}	1.5^{b}	2.0^{cd}	2.1^{de}	0.9^{b}	1.7^{d}	2.3^{f}
	Na_2	2.2^{cd}	2.3^{de}	2.5^{e}	1.8^{c}	2.3^{ef}	2.5^{f}	0.9^{b}	1.8^{d}	2.5^{g}
II	Na_0	1.2^{a}	2.1^{c}	2.3^{d}	0.4^{a}	1.4^{c}	1.9^{e}	0.2^{a}	1.0^{b}	2.0^{d}
	Na_1	1.5^{b}	2.3^{d}	2.3^{d}	0.6^{ab}	1.6^{d}	2.0^{e}	0.3^{a}	1.2^{c}	2.3^{e}
	Na_2	1.6^{b}	2.2^{cd}	2.3^{d}	0.7^{b}	1.7^{d}	2.3^{f}	0.3^{a}	1.1^{bc}	2.3^{e}
III	Na_0	0.6^{a}	1.7^{b}	2.2^{d}	0.3^{a}	1.2^{b}	1.8^{d}	0.2^{a}	1.1^{b}	2.1^{c}
	Na_1	0.8^{a}	2.0^{cd}	2.2^{d}	0.4^{a}	1.4^{bc}	1.8^{d}	0.2^{a}	1.2^{b}	2.4^{d}
	Na_2	0.8^{a}	1.9^{bc}	2.2^{d}	0.4^{a}	1.4^{c}	2.1^{e}	0.2^{a}	1.2^{b}	2.3^{d}

Each soil and harvest was tested separately. Means with same superscripts do not differ at p=0.05.

(8–11%) for the loam and the organogenic soil but for the clay it was below 4% in all treatments. By way of comparison, utilization of added K was 68–75% for the organogenic soil, 34–64% for the loam and 21–45% for the clay. The reserves of soil K decreased at the K_0 and K_1 levels for all the soils, for the organogenic soil also at the higher application rate (K_2) (Table 5). The

Table 5. Exchangeable Na and K concentrations of the experimental soils (mg dm^{-3}) before and after the pot experiment.

	Original	After the experiment			
			K_0	K_1	K_2
Na					
Clay	15	Na_0	18	14	13
		Na_1	208	174	191
		Na_2	364	353	543
Loam	8	Na_0	4	10	14
		Na_1	189	211	253
		Na_2	325	430	352
Organogenic soil	9	Na_0	3	5	4
		Na_1	132	168	195
		Na_2	276	325	353
K					
Clay	283	Na_0	78	172	256
		Na_1	78	152	310
		Na_2	83	130	313
Loam	134	Na_0	32	58	163
		Na_1	27	60	194
		Na_2	27	45	240
Organogenic soil	87	Na_0	19	33	66
		Na_1	19	32	55
		Na_2	23	30	69

total uptake of K by plants (three harvests) at the K_0 level was 325, 199 and 145 mg dm^{-3} for clay, loam and organogenic soil, of which 120, 89 and 76 mg dm^{-3} was non-exchangeable K, respectively.

Discussion

The Na concentration of timothy not fertilized with Na was up to 10 times higher in the present pot experiment than generally found in field conditions in Finland (Kähäri and Nissinen 1978, Jansson 1986) even though the experimental soils had an average Na status as compared to the soils of Finland (Sippola and Tares 1978). The high Na concentrations can partly be explained by a high N fertilization rate (450 mg dm^{-3} corresponding to 900 kg ha^{-1}). In field conditions, N fertilization of 600 kg ha^{-1} has increased the Na concentration of mixed ley by a factor of 6.7 as compared to unfertilized ley (Rinne et al. 1974). Due to the high Na concentrations of timothy in the present pot experiment, the results cannot be applied quantitatively to field conditions, but they give qualitative information about the different interactions between cations in the nutrition of timothy. In normal cultivation the plants are better supplied with K than in the K_0 pots of the present experiment. Therefore, the response of timothy to Na fertilization in field conditions would most likely be closer to that observed at the K_1 and K_2 levels and far from the higher responses measured in the K_0 pots.

The increased Na concentration of timothy caused by the application of K at the Na_0 level can be explained by cation exchange. Added K effectively displaces Na from the cation exchange sites of soil, as was shown in the Na/K exchange studies. A higher Na concentration in the soil solution consequently promotes Na uptake by timothy. However, the observed increase of Na concentration brought about by K application is marginal. The slight increase in plant K concentration upon Na addition in the K_0 treatment on loam and organogenic soil reflects the exchange between added Na and soil K.

Calcium is the dominating exchangeable cation in the soil, and the Na/Ca exchange equilibria suggest that added Na remained nearly completely in the soil solution. The particularly high selectivity for Ca of the organogenic soil is probably due to the complexation of Ca with the functional groups of organic matter (McBride 1994). In spite of the lowest selectivity for Na over Ca in the organogenic soil, the highest Na concentrations were obtained on the loam. At the end of the experiment the percentage of Na of the sum of cations (in mol of charge dm^{-3}) extracted by ammonium acetate was highest in the loam, the Na activity of the soil solution consequently being highest in this soil. The difference in Na activity in the soil solution may thus explain the difference in the Na concentration of timothy grown on the mineral and the organogenic soils. The high original Ca concentration of the organogenic soil may also have depressed the uptake of Na through cation antagonism. In K uptake the selectivity by plants seemed to dominate the selectivity in cation exchange. The difference in Na concentrations between the mineral soils is due to the larger reserves of K in clay.

Indeed, the most pronounced phenomenon in the present study was the dependence of Na uptake on the K supply, either in the form of native or added K. The effect of Na application on Na concentration of timothy for the three soils (organogenic soil$\gtrsim$loam>clay) was at odds with the K supplying power of the soils. The effect of the lower K supplying power of organogenic soils on the Na concentration of timothy was also evident in the study of Kähäri and Nissinen (1978). They reported higher Na concentrations of timothy in the province of Lappi, dominated by organogenic and coarse mineral soils, than in the rest of the country. They also observed that timothy grown on Sphagnum peat soils contained 122 mg Na kg^{-1} in contrast to the average around 50 mg kg^{-1} in timothy grown on other soils, without a marked difference in exchangeable Na in soil.

The increasing efficiency of Na fertilization towards the end of the experiment can, besides a decrease of the reserves of soil K upon K uptake by the plants, partly be caused by gradual filling of storage capacity for Na in roots and consequent transport of Na to shoots. Distinctively natrophobic timothy stores as much as 90% of Na taken up in the roots (Jarvis 1982). When this storage capacity is used up, the Na concentration of the shoots starts to increase. It has indeed been observed that the Na concentration of timothy increases when plants age (Jarvis 1982). The same phenomenon, in a weaker form, has been observed with perennial ryegrass, meadow fescue and cocksfoot (Rinne et al. 1974, Smith et al. 1980).

The effect of Na fertilization on the Ca concentration and K/(Ca+Mg) ratio of timothy was opposite to that observed with perennial ryegrass in field conditions (Chiy and Phillips 1993). However, in Chiy and Phillips' experiment, considerably natrophilic ryegrass was grown in suboptimal K conditions: Na fertilization increased the Na concentration of herbage substantially, increased the yield and Ca concentration and even lowered the K concentration of herbage. The apparent recovery of Na by ryegrass in that field experiment was 70%, which is considerably higher than in the present pot experiment. The difference between timothy and ryegrass supplied adequately with K would probably be smaller than these results suggest.

Conclusions

The present study shows that timothy has such a preference for K that even an excessive K concentration in a plant cannot be suppressed by ample Na additions. The strong reduction of Na uptake by native and added K makes it difficult to elevate the Na concentration of timothy sward by Na applications in practice. As long as K concentration of timothy is at a level sufficient for maximum growth or higher (luxury consumption), the Na concentration of shoots cannot be effectively increased by Na application. It is possible to elevate the Na concentration of timothy substantially only when plants are in K deficiency. However, a deficiency of K endangers the production of maximum yield and it may be unreasonable to produce grass high in Na at the expense of the yield. If Na is applied to timothy in field conditions, the utilization rate cannot be expected to be high. Other grass species like cocksfoot and ryegrass utilize Na more effectively (Smith et al. 1980, Jarvis 1982). Cultivation of these less natrophobic species as pure stands or as mixtures with timothy is a more realistic alternative to elevate the Na content of forage than Na fertilization of timothy.

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SELOSTUS

Timotein natriumlannoitus

Tommi Peltovuori ja Markku Yli-Halla
Helsingin yliopisto

Suomessa nurmikasvien natriumpitoisuus on paljon pienempi kuin lypsykarjan rehun pitoisuudeksi suositellaan. Nurmirehun Na-pitoisuuden kohottaminen parantaisi sen ravitsemuksellista laatua ja lisäisi joidenkin tutkimuksien mukaan rehun maittavuutta. Erityisen vähän natriumia on timoteissä. Astiakokeessa selvitettiin Na-lannoituksen (0, 200 tai 400 mg l^{-1} kokeen alussa) vaikutusta timotein Na-, K-, Ca- ja Mg-pitoisuuteen ja K-lannoituksen (0, 100 tai 200 mg l^{-1} jokaiselle korjatulle sadolle) vaikutusta Na-lannoituksen tehoon kolmella eri maalajilla.

Natriumlannoitus ei vaikuttanut timotein kuiva-ainesatoon, mutta se kohotti timotein Na-pitoisuutta selvästi kaikilla maalajeilla ja kaikissa korjatuissa sadoissa. Hieta- ja turvemailla vaikutus oli voimakkaampaa kuin savimaalla. Kaliumlannoitus ja maan suuri K-pitoisuus heikensivät Na-lannoituksen tehoa erittäin voimakkaasti. Natriumlannoitus toimi tehokkaimmin, kun timotein K-pitoisuus laski lähelle puutostilaa (alle 15 g kg^{-1}). Näin pieniin K-pitoisuuksiin päästiin vain ilman K-lannoitusta kasvaneissa koejäsenissä hieta- ja turvemailla. Natriumlannoitus pienensi jonkin verran timotein Ca-pitoisuutta, mutta ei K- eikä Mg-pitoisuutta. Natriumlannoituksen näennäinen hyväksikäyttöaste oli kaikilla mailla alle 4 %. Natriumia timoteitä tehokkaammin ottavien nurmikasvilajien (koiranheinä, raiheinä) viljely saattaa olla timotein Na-lannoitusta parempi keino nurmirehun Na-pitoisuuden kohottamiseksi.