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Effect of liming on yield and quality of peppermint and Sachalin mint in fine sand soil of Northern Finland

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Soil acidity commonly limits plant production in the fine sand soil of Northern Finland, which often has a low pH (5.5–6.5) and contains low levels of Ca and Mg. The effect of five liming (10% Mg and 19% Ca) levels, 0, 4, 8, 12, and 16 tons ha^{-1}, on the herb and essential oil yield and menthol and menthone content of two mint species (peppermint, *Mentha x piperita,* a variety of Black Mitcham and Sachalin mint, *Mentha arvensis* var. *sacchalinensis*) cultivated in fine sand soil in Northern Finland (64°40'N and 25°05'E) was studied during 1998–2000. Liming clearly increased the pH levels and the Ca and Mg content of the soil. The dry matter content, essential oil quantity, and the menthol or menthone content in mints were not affected by liming. In comparison with no liming however, liming at a rate of 4 t ha^{-1} doubled the herb yield. The highest yield was achieved in Sachalin mint by liming at 4 or 8 t ha^{-1} in the second and third year (soil pH 6–6.5) (Ca 725–871 mg l^{-1} and Mg 122–219 mg l^{-1}), and in peppermint by liming at 4, 8 or 16 t ha^{-1} (soil pH 6–6.6) (Ca 725–1272 mg l^{-1} and Mg 122–245 mg l^{-1}). Therefore, we conclude that a higher peppermint and Sachalin mint yield is achieved by increasing soil pH to values above 6.0 in the fine sand soil of Northern Finland.

Key words: Lamiaceae, lime, *Mentha arvensis* var. *sacchalinensis, Mentha x piperita,* menthone, menthol, pH, roots, stolons

Introduction

Over the past few years, different herb species have been a subject of continuous interest to consumers, growers, and researchers in Finland. Peppermint (*Mentha piperita* L.), a member of the *Lamiaceae* family, is a rhizomatous aromatic plant widely cultivated in many countries, such as the USA, India, China, the former USSR, Italy, France and Hungary. Its essential oil is considered industrially important (Lawrence 1985)

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as it is used in pharmaceuticals, confectionery, alcoholic beverages, chewing gum, dental creams and cosmetics, and its leaves are used in food flavoring, tea and folk medicine (Gupta 1991). Each year, Finland imports about 8 t of dry mint leaves, 10–20 t of peppermint essential oil, and 10 t of pure menthol (National Board of Customs 1984–1996). Many reports on the benefits of long days of sunlight for mint cultivation (Burbott and Loomis 1967, Clark and Menary 1980) make increasing Finnish production an attractive proposition.

Soil pH profoundly affects the growth and nutrient uptake by crops. Shukla et al. (1997, 1998) observed that different levels of soil pH influenced the fresh and dry weight and the essential oil yield of peppermint. It has been found that high levels of Mg in nutrient solution increase the leaf essential oil content of *Mentha arvensis* without significantly altering the quality of the essential oil (Zimma and Piekos 1988, Maia et al. 2001). The leaves of peppermint are rich in K and Mg (Berbec and Kolodziej 1996).

One of the factors limiting plant production in Finland is soil acidity; the average pH value of agricultural soils in 1981–1987 was 5.8 (Kähäri et al. 1987). The pH range in the fine sand soil of Northern Finland is 5.5–6.5, and liming is commonly needed. The acidic sandy soils of Northern Finland are also poor in Ca and Mg. It is to be expected that liming the soil is necessary in order to profitably cultivate mints in acidic soils.

At present, the cultivation of mint is very limited in Finland. In order to offer farmers in Northern Finland a new source of income, a project was started to examine the optimal conditions for the cultivation of mint. Because of favorable light conditions (long days) and cool nights, high quality essential oil yield can be expected (Franz 1984). In this particular study, the impact of liming (including the manipulation of soil pH and the contents of Ca and Mg) on the yield and quality of *Mentha x piperita* and *Mentha arvensis* var. *sacchalinensis* species was investigated during a three-year field experiment.

Material and methods

Plant material and the field experiment

The experiment was established in 1998 in Ruukki (Northern Finland) at the North Ostrobothnia Research Station of MTT Agrifood Research Finland, 64°40’N and 25°05’E. It was set up in a randomized split-plot design of four blocks (Gomez and Gomez 1984), where the main plots were laid out in each block according to a randomized complete block design. There were two main plots (mint species) in each block: 1) *Mentha x piperita* “Peppermint” (a variety of Black Mitcham, originally from Egypt) and 2) *Mentha arvensis* var. *sacchalinensis* (originally from Hungary).

Table 1 shows the experimental field treatment dates in 1998–2000. The amount of N, P, and K applied annually were 40, 28, and 56 kg ha^{-1}, respectively. The lime was spread manual-

Table 1. The treatment dates of the field experiments in 1998–2000.

Treatment	1998	1999	2000
Soil sampling	28 May and 15 Sep		11 May
Fertilizer application	7 Jun	7 Jun	22 May
Liming	7 Jun	–	–
Planting	9 Jun	–	–
Harvesting	27 Aug	17 Aug	15 Aug
Root and stolon development observation			16 Aug

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ly before fertilization and mixed immediately after being spread with an S-spike. The subplots received 0, 4, 8, 12, or 16 t ha^{-1} of lime. The lime was provided by Saxo Mineral Oy in Tornio (Northern Finland). The lime contained more than 10% Mg and more than 19% Ca. The fast acting neutralizing capability of liming was 35% of the material, according to the Finnish pH Stat Method. Determination of the neutralizing value was performed by the Finnish Plant Production Inspection Center (unpublished, as described by Erstad et al. 2000).

The plants were micropropagated. Nodal cuttings were cultured on Murashige and Skoog's (1962) medium for shoot regeneration and on Lloyd & McCown's woody plant medium (1980) for rooting. The rooted plants were planted after fertilization and liming in the experimental field in spring 1998. The plot size was 1.5 x 5 m (= 7.5 m^2); the distance between the rows was 75 cm and the distance between the plants in the rows was 20 cm.

Analyses

Samples for soil analyses were taken in May 1998 before liming and fertilization and in September 1998 and May 2000 after liming and fertilization (Tables 1 and 2). Five subsamples were taken from each subplot replication (liming level) and mixed in order to obtain one sample of approximately 0.5 l from each liming level. The sampling depth was 0–20 cm. In this experiment, an analysis of statistical error was not possible because only one sample per liming level was taken.

The samples were analyzed by Soil Analysis Service Ltd. The soil texture and organic matter content were estimated by finger assessment. The soil texture was that of fine sand containing 6–12% of organic matter. To analyze soil nutrients, 25 ml of soil was extracted with 250 ml of acidic ammonium acetate (pH 4.65) (Vuorinen and Mäkitie 1955) and a plasma emission spectrometer was used for the determinations. A spectrophotometer was used for the determination of P. After standing 12 hours, the soil pH and electrical conductivity (EC) were determined in soil-water suspension (1:2.5). A specific electrode was used to measure both the pH and EC in this suspension.The results of the analyses before liming and fertilizing were: soil texture, fine sand with 6–12% of organic matter content and electrical conductivity, 0.8 mS cm^{-1}, pH 5.8, and Ca 677, P 21, K 214 and Mg 41.6 mg l^{-1} of soil.

The fresh yield was determined after harvest: dried (at +40°C) random samples (2 x 200 g) were used to assess dry matter content and to estimate the concentration of essential oil. To

Table 2. The results of soil analyses after liming and fertilizing in 1998 and 2000.

Analysis	Liming level t ha^{-1}				
	0	4	8	12	16
September 1998					
pH	5.5	6.0	6.1	6.4	6.5
Ca mg l^{-1}	569	725	836	979	1270
P mg l^{-1}	26	25	25	25	26
K mg l^{-1}	141	119	128	127	138
Mg mg l^{-1}	48	122	168	202	223
May 2000					
pH	5.5	6.0	6.5	6.6	6.6
Ca mg l^{-1}	527	754	871	892	1272
P mg l^{-1}	23	25	24	22	24
K mg 1^{-1}	197	199	203	194	192
Mg mg l^{-1}	72	176	219	214	245

isolate the essential oil, mint leaves (50 g) were dried at +30°C and then mixed with 700 ml of water which was subsequently hydrodistilled for 2 h at 120°C at atmospheric pressure. The essential oil content was then measured (Pohjamo 1994).

The constituents of the essential oil were analyzed using GC and identified by GC/Ms. Sample preparation: Leaf samples, which were selected to represent leaves of all ages, were collected at random from randomly selected plants. Gas chromatography was performed with a Perkin Elmer Autosystem XL gas chromatograph using helium as the carrier gas at a constant pressure mode (37 psig).

The sample components were identified by mass spectra matching with a Wiley/NBS Registry Mass Spectra Data Base. The identifications were verified by comparing the retention time and mass spectrum with, when possible, a reference compound.

Root and stolon observation

When finishing the experiment, root and stolon samples were taken from each plot in the year 2000 in order to observe their development. The root density, the number of stolons, as well as the weight of roots and stolons, were measured. The density of roots and the number of stolons were evaluated on a scale of 1–4, in which 1 was remarkably few, 2 few, 3 optimum and 4 many. The observation dates are shown in Table 1.

Weather conditions during the experiment

The monthly average temperature in the summer 1998 was lower than normal in North Ostrobothnia and in the summer 1999, it was close to normal; in the year 2000, May and July were higher than normal (Table 3). The precipitation in the summers of 1998 and 2000 were higher than normal and in 1999, it was close to average.

Table 3. The monthly mean summer temperatures (°C) in 1998–2000 and long-term average in Ruukki. Data provided by the Finnish Meteorological Institute.

	Year			
Month	1998	1999	2000	1961–90
May	6.3	5.4	8.9	7.7
June	12.7	15.5	13.1	13.2
July	15.4	15.8	16.3	15.4
August	12.4	11.7	13.1	13.1

Statistical methods

The randomization method led to the split-plot experimental design. Hence, the response variables were analyzed using the traditional ANOVA for split-plot design (Gomez and Gomez 1984).

Measurements of fresh yield and essential oil content were repeated several times for each plot. The repeated measurements tended to correlate, which was taken into account in the model used. The covariance structure of the repeated measurements was chosen by comparing potential structures using Akaike and Schwarz's Bayesian information criterion (Wolfinger 1996). The model, and the assumptions used, was illustrated by Gumperetz and Brow (1993).

The assumptions in both models were checked graphically by box-plot in order to test the normality of errors; plots of residuals were used to test the constancy of error variance (Neter et al. 1996). The parameters of the models were estimated by the restricted maximum likelihood (REML) estimation method using the SAS system for Windows, release 8.1.

Results and discussion

Impact of liming on soil

Liming clearly increased the Ca and Mg content of the soil (Table 2). In Finland, there are no rec-

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ommended soil nutrient levels for herbs. According to Soil Analysis Service Ltd (1997), a Ca content of 1400–2000 mg l^{-1} and an Mg content of 120–200 mg l^{-1}, which is the targeted level, are satisfactory in fine sand soil used for growing outdoor vegetables. The Ca and Mg levels in the experimental field were initially lower than the ranges recommended by Soil Analysis Service (see Table 2) but the satisfactory values were achieved after liming.

In 1998, the soil pH in plots after liming with 4, 8, 12, and 16 t ha^{-1} were respectively 0.5, 0.6, 0.9, and 1.0 units higher than in plots with no liming: the pH range in liming levels in 1998–2000 was 6–6.6. Although liming was performed only in 1998, the soil pH levels in plots limed with higher amounts than 4 t ha^{-1} seemed to be higher in 2000 than they were in 1998, probably due to the slow dissolution of lime. Similarly, according to Kemppainen et al. (1993), after liming with 8 or 12 t ha^{-1} in the first year of trials, the pH level increased during the 7 years of experiment in fine sand while at 4 t ha^{-1} pH level, the pH rose only in the first year and remained the same during the 7 years. The recommended pH value for all soils is 6.5–7 (Soil Analysis Service 1997).

Yield, oil content, and menthol and menthone content

Liming had the most pronounced effect on fresh yield (Table 4). In 1999, the fresh yield of Sachalin mint was significantly, and for peppermint almost significantly, higher with liming in comparison with no liming (Table 4).

In 2000, the yields were much lower than in the two previous years, which was due to weeds, bad overwintering, and plant age. Galambosi (1995) also found a decrease in yields of biological mint in trials performed in South Mikkeli, Finland. Moreover, according to Hornok (1992), a peppermint plantation should be maintained for two, or rarely, for three years and it should not be cultivated in the same field for four years due to increases of weeds, insects, and diseases. In our experiment, however, all plants were healthy and no signs of disease were observed.

In this experiment, the effect of liming on the fresh yield of Sachalin mint was almost significant. The yield of Sachalin mint was higher with liming at a level of 4 or 8 t ha^{-1} (Soil pH 6–6.5) in comparison with no liming (soil pH 5.5). The highest yield of peppermint was also achieved

Table 4. Fresh yield of the Sachalin mint and peppermint (kg ha^{-1}) in 1998–2000 at different liming levels.

Species	Liming level t ha^{-1}					P-value*
	0	4	8	12	16	
Year 1998						
Sachalin mint	7867	12267	9600	13334	12400	0.06
Peppermint	16267	16667	16933	18266	17200	0.88
Mean	12000	14400	13333	15733	14800	0.11
Year 1999						
Sachalin mint	10933	24800	23733	23333	27866	<0.005
Peppermint	9200	16333	15867	14800	17600	0.05
Mean	10133	20400	19733	19067	22666	<0.001
Year 2000						
Sachalin mint	2800	7200	6600	2533	2133	0.05
Peppermit	1333	2120	2016	1466	1867	0.06
Mean	2060	4550	4250	1985	1888	0.08

P-value* = P-value between five liming level differences

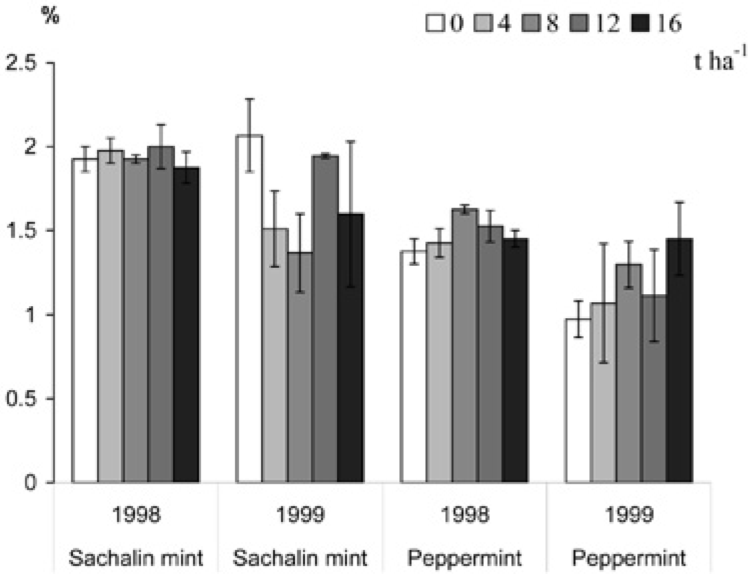

Fig. 1. Essential oil content (%) in dry leaves of Sachalin mint and peppermint in 1998–1999 at different liming levels.

with the liming level of 4 or 8 in comparison with no liming, but only in the second and third years (1998 and 2000) after application. The average yield for three years shows that liming with 4 t ha^{-1} gave almost the same yield as with 8 and 12 t ha^{-1}. Matusiewicz (1972) studied peppermint of the Mitcham variety for three years in five combinations of soil pH, ranging from 4.7 to 6.9. He concluded that the plants developed best and gave the highest crop of plant material at soil pH ranging from 5.6 to 6.2. In addition to low pH, the reason for low yield could also be Ca and Mg deficiency, which limited the yield in treatments when liming was not applied.

The dry matter content for Sachalin mint in 1998, 1999, and 2000 was 17–18%, 18–19%, and 17–19%, and for peppermint it was 13–14%, 19–20%, and 19–21%, respectively. Liming did not have any effect on the percentage of dry matter. Differences in dry matter were seen between different species ($P < 0.0001$) and between different years ($P < 0.0001$).

Liming did not affect the essential oil content of Sachalin mint ($P = 0.38$ in 1998 and $P = 0.16$ in 1999,) and peppermint ($P = 0.16$ in 1989 and $P = 0.71$ in 1999,) (Fig. 1). The slightly (0.02) higher essential oil yield was achieved in 1998 by liming in Sachalin mint (Fig. 2). In 1999, although the essential oil yield was higher with liming than without it, the differences in both mints were not significant because of the wide random variation. Wide random variation in essential oil yield is due to factors in the field other than genetic differences, as the plant material used in this experiment was micropropagated. The menthol and menthone content of Sachalin mint and peppermint were not influenced by liming (Table 5).

Development of rootage

Both the deficiency and excess of minerals has a negative effect on root growth. The effect of liming on the weight and density of roots in the soil was not significant, but Sachalin mint roots were longer ($P < 0.001$) in limed plots at the pH 6–6.5, in comparison with unlimed plots (pH 5.5). In peppermint, the difference in root length was not statistically significant (Table 5).

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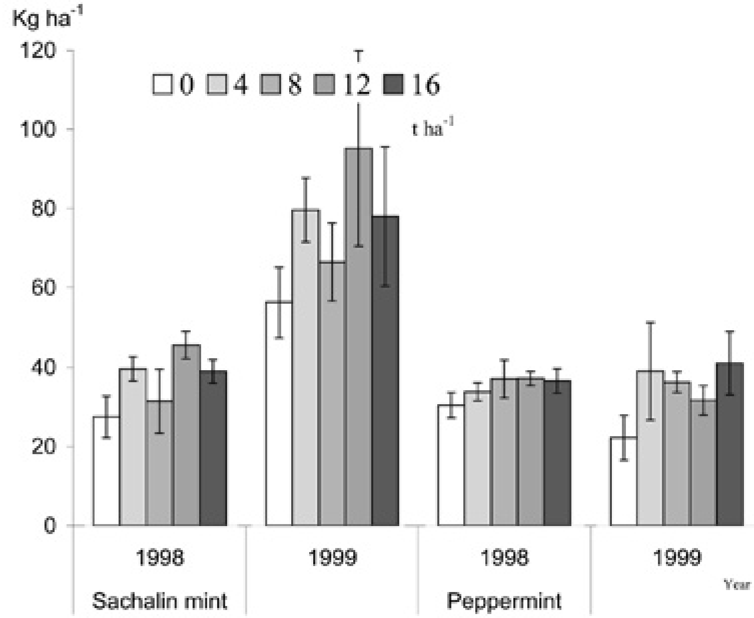

Fig. 2. Essential oil yield (kg ha^{-1}) of Sachalin mint and peppermint in 1998–1999 at different liming levels.

Table 5. The growth of mint rootage and contents of menthol and menthone (%) of total peak area at different liming levels.

	Liming levels t ha^{-1}						Significance
	0	4	8	12	16	SEM	P1
Sachalin mint							
Root density per plant, 1–4 scale*	1.8	2.0	2.3	1.8	2.0	0.28	0.25
Number of stolons per plant, 1–4 scale*	1.5	2.3	2.0	1.8	2.0	0.29	0.14
Root and stolons, g per plant	124	162	277	135	235	79.0	0.38
Root length, cm per plant	11.9	15.8	18.3	16.5	22.8	2.44	<0.001
Menthol %	82.5	81.8	80.8	82.5	82.9	1.53	0.88
Menthone %	10.5	8.90	9.20	8.40	7.60	1.09	0.54
Peppermint							
Root density per plant, 1–4 scale*	3.8	3.5	3.5	4.0	3.0	0.28	0.41
Number of stolons per plant, 1–4 scale*	3.5	3.0	3.8	4.0	3.0	0.29	0.85
Root and stolons, g per plant	656	642	599	736	441	79.0	0.56
Root length, cm per plant	19.5	22.3	21.5	22.8	20.3	2.44	0.40
Menthol %	53.5	46.3	51.3	48.9	52.0	3.94	0.72
Menthone	20.5	24.8	22.1	22.2	22.2	4.72	0.98

SEM = standard error of mean
P1 = P value between 0 and other lime level
Scale* 1 = remarkably few, 2 = few, 3 = optimum and 4 = abundant

Summary and conclusions

By applying 4 t ha^{-1} of lime, the pH rose from 5.5 to 6 in fine sand soil with 6–12% organic matter content. Liming almost doubled the fresh herb yield of both Sachalin mint and peppermint. The essential oil yield was higher in Sachalin mint in the first year. Liming had no effect on the essential oil content and proportion of menthol and menthone; neither did it have any effect on the development of peppermint rootage. However, liming at the level of 4 or 8 t ha^{-1} (pH 6–6.1) did have a positive effect on the length of roots in Sachalin mint.

In conclusion, if the soil pH value is lower than 6 or the Mg and Ca are low, liming at the level of 4–8 t ha^{-1} in the sandy soil of Northern Finland is recommended in order to achieve a higher fresh yield and a higher essential oil yield. Liming with 12 t ha^{-1} produces almost the same yield as with 4 t ha^{-1} during the first three years after liming. Liming has no effect on the essential oil content, the proportion of menthol and menthone, or the percentage of dry matter. The roots of Sachalin mint are longer with liming.

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SELOSTUS

Kalkituksen vaikutus piparmintun ja Sachalinin mintun satoon Pohjois-Suomessa

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Maan happamuus rajoittaa yleisesti kasvien tuotantoa Pohjois-Suomen hienohietamailla, joiden pH vaihtelee 5,5–6,5 ja kalsium- ja magnesiumtaso ovat yleensä alhaisia. Kalkituksen vaikutusta kahden mintun (piparminttu, *Mentha x piperita,* lajike Black Mitcham ja Sachalinin minttu, *Mentha arvensis* var. *sacchalinensis*) satoon sekä haihtuvan öljyn määrään, mentoli- ja mentonipitoisuteen tutkittiin Pohjois-Suomessa vuosina 1998–2000. Kalkkia (10 % Mg ja 19 % Ca) levitettiin joko 0, 4, 8, 12 tai 16 t/ha. Maalaji oli hienoa hietaa.

Kalkitus nosti selvästi maan pH:ta sekä kalsium- ja magnesiumtasoa. Kalkitus ei vaikuttanut sadon kuiva-ainepitoisuuteen, öljyn määrään eikä mentolin tai mentonin pitoisuuteen. Neljä t/ha kalkkia saaneilta aloilta tuoresato oli kaksi kertaa suurempi kuin aloilta, joita ei oltu kalkittu. Sachalinin mintun sato oli suurin, kun sitä kalkittiin 4–8 t/ha toisena ja kolmantena vuonna (maan pH 6–6,5, Ca 725–871 mg/l and Mg 122–219 mg/l). Piparmintun sato oli suurin, kun sitä kalkittiin 4, 8 tai 16 t/ha (maan pH 6–6,6, Ca 725–1272 mg/l ja Mg 122–245 mg/l). Näin ollen Pohjois-Suomen hienolla hietamaalla voidaan saada hyvä piparmintun ja Sachalinin mintun sato, kun maan pH on yli 6.