The European Journal of Plant Science and Biotechnology ©2011 Global Science Books

Greenhouse Study and Field Observations of Nutrient Disorders in Nordmann Fir (*Abies nordmanniana*) Christmas Trees in Norway

Venche Talgø[1,2] • Peder Lombnæs[3*] • Arne Stensvand[1,2]

[1] Norwegian University of Life Sciences, Department of Plant and Environmental Sciences, 1432 Ås, Norway
[2] Norwegian Institute for Agricultural and Environmental Research, Plant Health and Plant Protection Division, 1432 Ås, Norway
[3] Norwegian Institute for Agricultural and Environmental Research, Høgskoleveien 7, 1432 Ås, Norway

Corresponding author: * **peder.lombnaes@bioforsk.no**

ABSTRACT

Current season needle necrosis (CSNN) is a needle disorder on fir (*Abies* spp.) that has been associated with low calcium (Ca) foliage concentration in the USA. Shortly after bud break, randomly distributed needles form chlorotic spots that turn necrotic during the growth season. Another major needle disorder on fir is discoloured needle tips on two-year-old needles caused by Mg deficiency. The latter disorder is much more uniform than the former, i.e. all two-year old needles show symptoms. CSNN on the other hand, result in a mixture of healthy and diseased needles. Thus, the effects of low and sufficient supply of both Ca and Mg on plant mineral status were investigated on Nordmann fir (*A. nordmanniana*) grown in chelator-buffered nutrient solution in a greenhouse trial. Ca deficiency induced general chlorosis on new shoots, but no CSNN or Mg deficiency symptoms were obtained by suboptimal Ca and Mg supply. In field studies, no links were found between CSNN symptoms and Ca nutritional status.

Keywords: calcium, chelator-buffered nutrient solution, magnesium, manganese, potassium

INTRODUCTION

In Norway and many other European countries, Nordmann fir (*Abies nordmanniana*) is the dominant Christmas tree species. Two major disorders significantly affect the marketability of the trees; current season needle necrosis (CSNN) and magnesium (Mg) deficiency (Terje Pundsnes, Norwegian Extension Service, personal communication).

CSNN appears on new needles two-three weeks after bud break as tan to yellow-coloured spots or bands, which turn reddish brown during summer. Discoloured portions may occur at any position on a needle, and damaged needles are randomly distributed in the foliage. CSNN is a major problem on fir Christmas trees and bough plants in Europe and North America. The symptoms have been observed on noble (*A. procera*), Nordmann, and grand fir (*A. grandis*) on both continents. In the USA, research indicated that CSNN was a physiological disorder, and foliar applications of calcium significantly reduced CSNN damage (Chastagner *et al,* 1997). Another hypothesis in Europe suggested a biotic (fungal) cause to the CSNN-problem (Butin and Pehl 1993; Perny *et al*. 2002; Talgø *et al.* 2007).

In Norwegian field sites, low Mg uptake is known to induce chlorosis of the distal half of all needles on the previous year's shoots (very uniform symptoms). In severe cases, the chlorotic parts of the needles turn necrotic. Magnesium deficiency is also recognised as a nutritional constraint in true fir Christmas tree species in other European countries, ex. Austria (Perny *et al.* 2002) and Denmark (Lyhr 1994).

Based on the suggested role of Ca in CSNN development, we conducted an experiment with Nordmann fir transplants grown in nutrient solution (**Fig. 1A, 1B**). Suboptimal and sufficient levels of both Ca and Mg were included. Magnesium was included as an experimental factor due to the role of Mg-deficiency under field conditions (Kolling *et al.* 1997; Bouya *et al.* 1999), and the potential antagonistic relationship between Ca and Mg, as both being divalent macro cations. Prior to this experiment, chelator-buffered nutrient solution experiments were carried out with barley, oat, and wheat (Lombnæs and Singh 2003a, 2003b), but this was the first experiment with a lignose crop. At the farm level, both foliar and soil applications are common management strategies for controlling disorders. However, it has often been difficult to find an optimal balance for nutrient requirement and uptake. Few scientific studies have been undertaken to optimize nutrient supply to fir Christmas trees, thus fertilizer recommendations are not well developed, resulting in nutrient disorders *in situ*. Here, we present some examples of nutritional disorder symptoms from Norwegian field sites.

The main aim of the study was to state the role of Ca and possibly other nutrient disorders in development of classical CSNN symptoms, both by a controlled experiment in a greenhouse and by field observations. Furthermore, we wanted to state the cause of different other symptoms observed under field conditions that we expected to be caused by unbalanced nutrient levels. Specific objectives for the study were to investigate if: i) a low supply of Ca and possibly Mg could develop CSNN symptoms in *A. nordmanniana*; ii) there are possible synergetic and/or antagonistic effects of calcium and/or magnesium supply on the uptake and translocation of selected macro- and micronutrients; iii) some disorders observed under field conditions, including CSNN, might be associated with unbalanced nutrient levels.

Preliminary results were published elsewhere (Talgø *et al*. 2005; Lombnæs *et al.* 2008).

Received: 9 February, 2011. Accepted: 31 March, 2011.

Original Research Paper

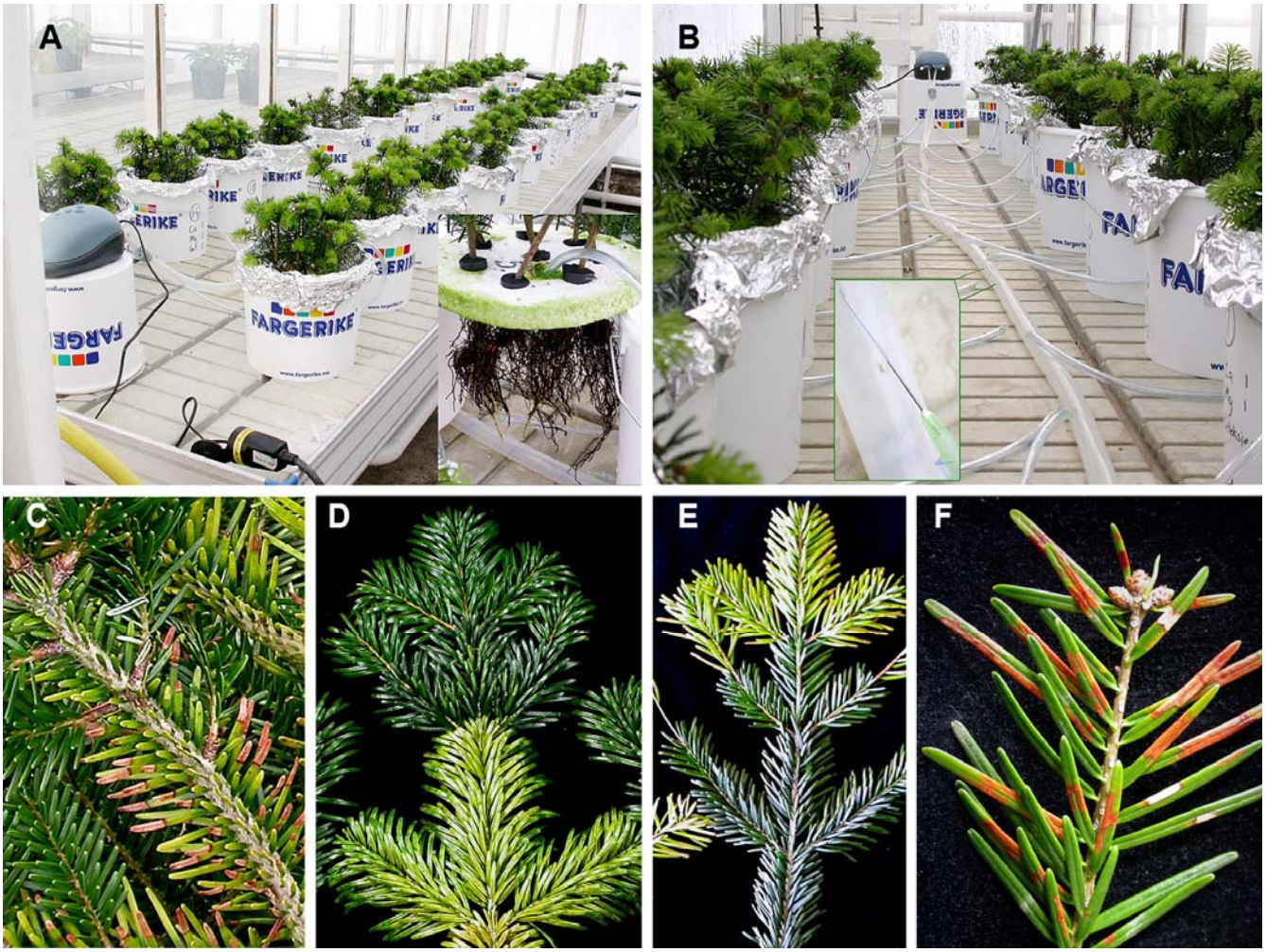

Fig. 1 Nordmann fir (*Abies nordmanniana*). (**A, B**) Experiment conducted in chelator buffered nutrient solution. (**C**) Chlorotic and necrotic needle tips on two year old foliage due to Mg deficiency (note that the current year shoots appear healthy). (**D**) Chlorotic old needles due to K deficiency (old needles became chlorotic from tip to base). (**E**) Chlorotic current year foliage due to Mn deficiency. (**F**) Discoloured patches on needles due to current season needle necrosis (CSNN). Photos: Venche Talgø.

MATERIALS AND METHODS

Greenhouse study

1. Plant growth

Two-year-old Nordmann fir container transplants (provenance Ambrolauri/Tlugi from Georgia in Caucasus) were grown for 31 days in chelator-buffered nutrient solution in a greenhouse (**Fig. 1A, 1B**). The average stem length at the start of the experiment was 15 cm. Fresh weight per plant, including roots, was approximately 12 g. The shoot: root ratio was approximately 1.5. Nutrient analysis were performed on a bulk sample (n = 25) before start of the experiment. The plants had been stored over winter at –2°C prior to the start of the experiment in mid-June. The experiment included 24 plastic containers with 4.0 litres of nutrient solution in each. In each container 8 transplants were carefully fixed in circular styrofoam lids (**Fig. 1A**). Holes for the plants were made with a cork borer. The lids were fitted to the containers and were floating on top of the solution. Edges of the containers were covered by aluminium foil to avoid light entering the nutrient solution between the lids and the container walls. The plants were kept in an upright position by fitting a water pipe insulation material between the stem basis and the walls of the holes in the styrofoam lid. Prior to transferring the plants to the containers, soil was washed from the roots with deionised water.

The average greenhouse temperature was 23.7°C (varied from 17.6 to 34.6°C) during the experimental period. Average mid-day photo fluency rate right above the plants was 295 µE m^{-2} s^{-1}. The containers were systematically rotated clockwise around the table every second day to ensure uniform light conditions during the experimental period. The nutrient solutions were changed weekly, and solution pH was controlled and adjusted daily with 1 M NaOH. The pH was consequently dropping from 6 to an average level of 4.5 during the 24-h periods. The containers were supplied by air from an aquarium pump. The air passed through a main silicon pipe to smaller PVC pipes entering the containers. The smaller pipes were connected with syringe needles to the main pipe (**Fig. 1B**).

2. Solution composition

The basal hydroponic solution was prepared with deionised water and contained 1 mM KNO_3, 80 µM KH_2PO_4, 0.5 mM $(NH_4)_2SO_4$, 3 mM NH_4NO_3, 0.01 mM H_3BO_3, 0.5 mM NaOH, 75 µM $Fe(NO_3)_3$, 8.0 µM $ZnCl_2$, 0.6 µM $MnCl_2$, 2.0 µM $CuCl_2$, 0.1 µM $NiCl_2$, and 0.1 µM $NaMoO_4$. The pH in the solution was buffered at 6.0 with 1.0 mM 2-[*N*-morpholino]ethanesulfonic acid (MES). Sufficient and suboptimal levels of Ca were provided by 2 mM and 0.04 mM $CaCl_2$, respectively. Corresponding levels of Mg was provided by 0.5 mM and 0.01 mM $MgCl_2$, respectively. HEDTA [*N*-(2-hydroxyethyl)-ethylenediamine-triacetic acid] was added at a concentration equal to the sum of the trace metal concentrations, plus a 25 µM excess (Parker *et al.* 1995; Rengel 1999; Pedler *et al.* 2000). The experiment included four factor combinations with sufficient and suboptimal levels of Ca and Mg in the nutrient solution.

3. Plant harvest and analysis

At the end of the experimental period, the plants from each container were rinsed in deionised water and divided into four samples: Current year shoots, old needles, stems and roots. The fresh

Table 1 Nutrient concentrations of selected elements in new shoots, old needles, stems, and roots of Nordmann fir (*Abies nordmanniana*) at low (0) and sufficient (1) supply of calcium (Ca) and magnesium (Mg) after 31 days growth in chelator-buffered nutrient solution.

		Macro nutrients (% of dry matter)					Micro nutrients (mg kg^{-1} dry matter)	
Plant part	**Treatments**	**N**	**P**	**K**	**Ca**	**Mg**	**Mn**	**Zn**
New shoots								
Ca	0	1.80 a*	0.29 a	1.30 a	0.05 b	0.07 b	77.6 b	26.3 a
	1	1.77 a	0.24 b	1.11 b	0.08 a	0.08 a	126.3 a	26.1 a
Mg	0	1.84 a	0.27 a	1.24 a	0.07 a	0.07 a	100.6 a	27.7 a
	1	1.72 b	0.26 a	1.17 a	0.07 a	0.07 a	103.2 a	24.6 a
Old needles								
Ca	0	1.84 a	0.20 b	0.70 a	0.71 a	0.17 a	658.0 a	89.8 a
	1	1.82 a	0.27 a	0.75 a	0.71 a	0.19 a	688.0 a	92.2 a
Mg	0	1.86 a	0.23 a	0.71 a	0.74 a	0.18 a	710.0 a	99.2 a
	1	1.80 a	0.24 a	0.74 a	0.68 a	0.18 a	637.0 a	82.8 b
Initial**		2.24	0.37	1.24	0.69	0.22	577.0	81.1
Stems								
Ca	0	1.30 a	0.13 a	0.50 a	0.19 b	0.09 a	216.0 a	43.0 a
	1	1.11 b	0.14 a	0.50 a	0.24 a	0.09 a	196.0 a	45.1 a
Mg	0	1.18 a	0.13 a	0.49 a	0.23 a	0.08 a	211.0 a	49.6 a
	1	1.23 a	0.14 a	0.51 a	0.21 a	0.09 a	200.0 a	38.5 b
Initial		2.09	0.40	1.20	0.32	0.19	301.0	79.0
Roots								
Ca	0	1.54 a	0.16 b	0.23 b	0.13 b	0.13 a	49.8 a	29.6 a
	1	1.50 a	0.22 a	0.36 a	0.40 a	0.09 b	44.0 a	37.2 a
Mg	0	1.53 a	0.19 a	0.30 a	0.31 a	0.08 b	53.0 a	40.0 a
	1	1.51 a	0.19 a	0.28 a	0.23 b	0.14 a	40.8 b	26.8 b
Initial		0.94	0.27	0.96	0.31	0.17	223.0	128.0

* Mean values of 12 replicates. For each of the two treatments per element per plant part, means with different letters in the same column and row are significantly different at P = 0.05 (Tukey's test).
** Initial = values at start of the experiments, mean values for 25 plants.

weight of the samples was recorded before they were transferred to paper bags and dried at 75°C for one week. Dry weight was recorded, and the samples were analysed for all essential macro and the most important micro minerals (**Table 1**). Before starting the experiment, a bulk sample of 25 plants was randomly chosen, and needles, stems, and roots were prepared for chemical analysis. Standard methods were used for the nutrient analysis; nitrogen (N) was analyzed by CHN-analysator (carbon, hydrogen, and nitrogen), and all the other elements by ICP (inductively coupled plasma).

4. Statistical analysis and software

The experiment was designed as a 2×2 factorial design, and included six replicate observations (in 6 separate containers) for each of the four factor combinations. Data were statistically analyzed with the ANOVA glm procedure of Minitab Statistical Software, and means were separated by Tukey's test. The statistical analyses were run both with and without interaction effects.

Field observations

A number of different disease and nutrient disorder symptoms were observed on foliage in Nordmann fir Christmas tree fields from 2000-2008. Samples with disorder symptoms were collected and analysed for macro- and micronutrients. The main production of Nordmann fir in Norway is in Rogaland County, hence, most samples originated from that region. Samples were taken from single trees, and foliage was divided into current and previous year needles, and occasionally 3-year-old foliage, roots, and stems were analyzed. The methods for chemical analysis were the same as for the Greenhouse trial.

RESULTS

Greenhouse study

Table 1 presents the nutrient concentrations and main effects of essential minerals at the end of the experiment in new shoots, old needles, stems, and roots, respectively. All results report the statistical analysis without interaction effects, because significant interaction effects were only present for Mg in roots ($p < 0.001$) (**Fig. 3**) and shoots ($p = 0.047$). Nutrient concentrations before start of the experiment (initial values) are based on the bulk sample (n = 25), and are given in the table.

In new shoots, Ca supply had a significant impact on several elements. Sufficient Ca-supply increased the uptake of Ca, Mg and Mn, and decreased the uptake of P and K. The only significant impact of adequate Mg supply was a negative influence on the uptake of N. By harvest time the new shoots were well developed (fully grown), but no CSNN symptoms were observed. A general chlorosis was seen on the new shoots in all the 12 replicates (containers) with low Ca supply.

In old needles, sufficient Ca supply increased the concentration of P, while Mg supply decreased the concentration of Zn. No disorder symptoms were observed on old needles. In stems, sufficient Ca supply decreased the concentration of N and increased the concentration of Ca, while sufficient Mg supply reduced the concentration of Zn. In roots, sufficient Ca supply increased the concentration of P, K, and Ca, and decreased uptake of Mg. Sufficient Mg supply increased the concentration of Mg, but decreased the concentrations of Ca, Mn, and Zn.

Field observations

Based on analysis of nutrient contents in field samples from Nordmann fir, a number of observed symptoms could be related to lack of specific minerals. **Fig. 1C-E** shows Mg deficiency, K deficiency, and Mn deficiency, respectively. Mg deficiency was recognised by chlorotic or necrotic two year or older needle tips. K deficiency showed up on the same needle generations as Mg deficiency, but was distinguished from the latter by needles turning chlorotic also at the base (not only the tip). Mn deficiency gave chlorotic current year shoots. N deficiency also gave chlorosis on the last year growth, but in addition older needles turned chlorotic. Thus, a more general chlorosis was seen with N deficiency compared to Mn deficiency.

Table 2 gives examples of nutrient content in Nordmann fir related to deficiencies of Mg (I and II), Mn (III and IV), and K (V). In addition current year needles with and without CSNN symptoms are included (VI and VII). Concerning the latter samples, the healthy needles were

Table 2 Nutrient content in Nordmann fir (*Abies nordmanniana*) Christmas trees with magnesium (- Mg), manganese (- Mn), potassium deficiencies (- K), and current season needle necrosis (CSNN) symptoms. A = latest/current year growth, B = previous year growth, C = three year old growth, S = stems, R = roots, H = healthy trees.

Sample site* / symptoms		Macronutrients (% of dry matter)					Micronutrients (mg kg^{-1} dry matter)	
		N	P	K	Ca	Mg	Mn	Zn
I / - Mg	A	1.37	0.17	0.72	0.43	0.06	1010.0	58.1
	B	1.51	0.13	0.49	0.34	0.03	916,0	46.2
	S	0.52	0.08	0.48	0.39	0.10	469.0	62.0
	R	0.75	0.13	0.62	0.20	0.13	167.0	68.2
II / - Mg	A	2.61	0.44	1.17	0.80	0.08	285.0	175.0
	B	1.93	0.30	0.89	1.21	0.05	606.0	282.0
	S	0.84	0.14	0.58	0.60	0.13	205.0	115.0
	R	1.34	0.38	0.77	0.58	0.15	101.0	440.0
III / - Mn	A	0.85	0.12	0.78	0.37	0.07	42.9	25.6 45.2
	B	1.20	0.10	0.66	0.70	0.05	107.0	15.6
IV / - Mn	A	1.49	0.19	0.80	0.37	0.09	3.2	16.5
	B	1.37	0.14	0.71	0.78	0.09	4.6	24.1
V / - K	A	1.75	0.17	0.71	0.18	0.09	209.0	28.0
	B	1.68	0.18	0.59	0.22	0.09	259.0	26.2
	C	1.19	0.09	0.40	0.20	0.08	198.0	46.6
VI / CSNN	A	1.61	0.33	0.83	0.54	0.13	112.0	64.5
	AH	2.23	0.35	0.96	0.61	0.13	102.0	80.2
VII/ CSNN	A	1.51	0.31	0.82	0.52	0.13	27.5	90.8
	AH	1.59	0.32	0.91	0.55	0.12	17.9	
Ref. values**	Min Max	1.6	0.14	0.6	0.1	0.06	50	15
		2.0	0.20	1.0	0.9	0.11	2500	50

* Commune/County: I = Strand/Rogaland, II = Suldal/Rogaland, III = Nøtterøy/Vestfold, IV = Finnøy/Rogaland, V = Hjelmeland/Rogaland, VI = Randaberg/Rogaland, VII = Time/Rogaland.

** Reference values = optimal nutritional values (minimum and maximum) (Christensen *et al.* 1997)

Fig. 2 County map of southern Norway. Sample sites from **Table 2** are marked (I – VII).

collected in the same field as the diseased needles (**Fig. 1F**), but from trees with no CSNN symptoms. All samples in **Table 2** originated from Rogaland County in southwestern Norway, except the first mentioned Mn deficiency samples (III), which was collected in Vestfold County in southeastern Norway (**Fig. 2**). The images of Mn and K deficiencies in **Fig. 1** are identical to sample IV and V, respectively.

The reference values in **Table 2** are optimal nutritional contents (range of nutrient content without nutrient disorder symptoms) for Nordmann fir recommended by HedeDanmark a/s in Denmark (formerly Hedeselskabet Forest and Landscape A/S) (Christensen *et al*. 1997). The values were based on data from nearly 100 locations (Ravnsbæk 1989). The content of the respective minerals in the samples showing deficiencies of Mg, Mn, and K were below the minimum reference values.

DISCUSSION

In the greenhouse study, we were interested in symptom development on young needles to find out if CSNN could be related to low Ca content. In the suboptimal Ca treatments, Ca concentration in new shoots (**Table 1**) was reduced to approximately 50% compared to reference values given in **Table 2**; however, no CSNN symptoms were observed. Thus, we concluded that CSNN may not be triggered by low Ca concentration in needles. The latter was supported by our field observations, where there were only marginal differences in Ca concentrations in current year shoots with and without CSNN symptoms, and the Ca values of both diseased and healthy needles were well within the reference values (**Table 2**). This result supports the most recent research that suggests that CSNN seem to be associated with a fungal infection (Talgø *et al.* 2008, 2010). Also the random distribution of symptomatic needles in the foliage sup-ports the explanation that CSNN is caused by a biotic factor. The significant effect of foliar application of Ca against CSNN in USA may be explained by a fungicide effect of the Ca treatment (Gadoury *et al.* 1994).

We believe the general chlorosis we observed on the new shoots with low Ca supply in the greenhouse trial was due to low Mn concentration. Low Ca supply significantly suppressed Mn uptake in the new shoots. This may indicate that Ca has a specific function in the translocation process of Mn to new shoots, since there was no significant effect of Ca supply on the Mn concentration in roots, stem or old needles. Manganese deficiency is generally known to reduce chlorophyll conctent (Marschner 1995), and may induce chlorosis (Lombnæs and Singh 2003a). The symptoms correspond well with our field observations (**Table 2, Fig. 1E**), and with literature stating that lack of Mn induces chlorosis on younger leaves (Thompson and Huber 2007). Mn has a rather low translocation rate in plants compared to other nutrients (Mengel and Kirkby 1987; Pearson and Rengel 1994). Due to the immobile nature of Mn in plants, older foliage usually contains a higher amount of Mn compared to younger tissue (Singh and Steenberg 1974). Mobility of Mn in plants is slightly more mobile in stems and roots compared to foliage (Thompson and Huber 2007). The latter was confirmed in the present greenhouse trial; the Mn level was high in old needles, but lower in stems and roots. Especially the Mn concentration in the roots dropped considerably during the experimental period from more than 200 mg kg^{-1} to approximately 50 mg kg^{-1}.

Old needles were almost unaffected by different Ca and Mg treatments, but sufficient Mg supply had a negative im-

pact on Zn uptake. Generally, Mg^{2+} competes with Zn^{2+} and reduces the uptake of the latter (Ross 1975). This phenomenon was also obvious for roots and stems. No Mg deficiency symptoms were observed on old needles. The Mg concentration was slightly reduced during the experimental period compared to the initial value (**Table 1**), although still far above reference values for Mg (**Table 2**). Since the plant Mg status was rather high at the experimental start, we would probably have had to run the experiment for a longer period of time than 31 days in order to obtain Mg deficiency symptoms.

Mg is known to be mobile in plants, and when constrained, Mg is translocated from old to young needles (Lange *et al*. 1987). Interestingly, in our greenhouse study we noticed that in the low Mg treatments, when compared to initial values (**Table 1**), Mg-concentrations in stems and roots had been reduced considerably at the end of the experiment compared to old needles. This may indicate that, Mg for development of new shoots was primarily taken from stems and roots. By first using Mg from stem and roots before old needles, photosynthesis most likely remained unaffected for a longer period of time under conditions where Mg otherwise would be a constraining growth factor.

In general in the greenhouse study, Ca supply significantly increased the Ca concentration in all plant parts except old needles. Sufficient Ca supply also increased the shoot Mg concentration, suggesting a synergistic effect. The opposite relationship was obvious for the roots. This indicated that Ca had a positive effect on Mg translocation when first taken up by the plant, while a significant antagonism was valid for the roots. Both Ca and Mg had a mutual antagonistic relationship on the uptake of Ca and Mg in roots. Sufficient Ca supply significantly increased the amount of P and K in roots and P in old needles, but decreased the content of both elements in new shoots. Concerning the clear interaction effect ($p < 0.001$) for Mg in roots, we can conclude that the two factors (solution concentration of Ca and Mg) act dependently of each other (**Fig. 3**). Further, **Fig. 3** shows that Mg root concentration is less influenced by Ca supply when Mg supply is low. We consider the significant interaction effect for Mg concentration in shoots ($p = 0.047$) as too weak to draw any conclusion.

Sufficient Ca supply decreased the amount of N in stems, and sufficient Mg supply slightly decreased the amount of N in new shoots. This may indicate antagonistic relationship between the divalent cations and N. Many factors can cause Mg deficiency under field conditions. Even if chemical analysis of soil samples shows that Mg is present in sufficient amount, various soil factors may induce Mg deficiency; too high or too low pH, excess potassium, or too wet or too dry conditions (Aasen 1997). Antagonism, causing imbalance in nutrient uptake, may lead to negative nutritional effects. High pH may give Ca^{2+}/Mg^{2+} antagonism, too low pH may give NH^{4+}/Mg^{2+} antagonism, and abundant K may give K^{+}/Mg^{2+} antagonism (Aasen 1997). During wet conditions K+ and other monovalent cations may leave the colloids to regain equilibrium between liquid and solid material. Then Mg^{2+} may easily bind to the free spaces on the colloids, and thereby becomes unavailable for the plants. If the soil is very dry there may not be enough liquid for the nutrients to be dissolved, and thus uptake inhibited. Mg is the central atom in the chlorophyll molecule, hence, lack of Mg results in breakdown of chlorophyll and thereby chlorosis and necrosis (Aasen 1997). Potassium deficiency is not very common in Nordmann fir in Norway (Talgø *et al.* 2005). As for Mg, it is a very mobile nutrient in plants, and therefore easily translocated from older to younger needles.

Manganese deficiency is a less common disorder than Mg deficiency, but can be a nutritional constraint in certain locations. Manganese is not subject to relocation in the plants, and is nearly immobile after it has been transported to the cells, and therefore unavailable for the young shoots. Deficiency is most common on trees grown in soil with high pH (Ca^{2+}/Mn^{2+} antagonism)

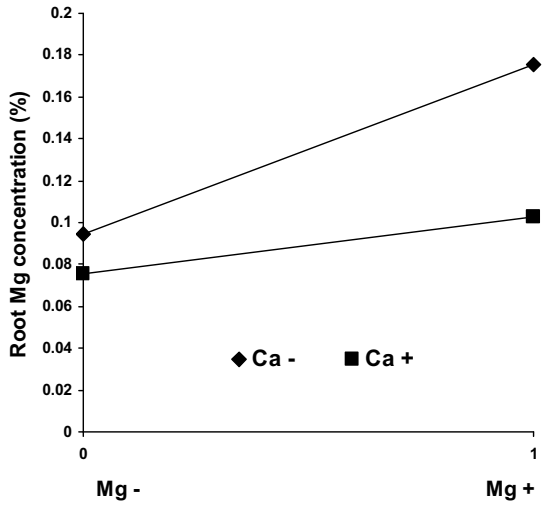

Fig. 3 Magnesium concentration in roots at the four treatment combinations and the interaction effect.

In Norway and other Christmas tree producing countries, there has been a major change in the production over the last decades, shifting from Norway spruce (*Picea abies*) in forest stands to fir (*Abies* spp.) on cultivated land. Thus, many Christmas tree fields are newly established on cultivated land. In general, pH is higher in cultivated soils than in forest stands, and may partly explain the two major abiotic problems we face on cultivated land; Mg and Mn deficiencies. It should be noticed that in cases of low Mn content, Mn deficiency symptoms do not necessarily occur. The healthy tree in sample VII in **Table 2** did not show any symptoms of Mn deficiency, even though the Mn content was below reference values, and also lower than in sample III where clear Mn deficiency symptoms were seen. This may serve as an example of the complex nature of nutrient balances in plants, with Christmas trees being no exception.

Standard levels of optimal nutrient concentrations were chosen in the sufficient treatments. We could have omitted Ca and Mg in the deficient treatments; however, we chose to adjust the levels to 2% of the sufficient treatment concentrations to avoid mortality of plants and at the same time achieve deficient conditions. This range of deficient vs. sufficient supply has commonly been practiced for other elements at higher plant species in nutrient solution experiments (Lombnæs and Singh 2003a, 2003b).

Our result showed no association between low Ca or Mg content and CSNN. Research and management focus should now be on a fungal infection as the cause of CSNN, and more precisely on *Sydowia polyspora* (Talgø *et al.* 2010). Nutrient disorders and their causes have not been extensively studied in Christmas tree production previously and should receive more attention in the future. However, results from our field observations made it possible for growers to identify the major nutrient deficiency problems, and fertilize accordingly. Especially against Mg deficiency, foliar applications of Mg has proven very effective if applied on new shoots before they become lignified and the wax layer is still developing on the needles.

ACKNOWLEDGEMENTS

We want to thank Marit Larssen Sekse at The Norwegian Institute for Agricultural and Environmental Research, and Terje Pundsnes in The Norwegian Agricultural Extension Service (NLR) for valuable technical assistance.

REFERENCES

Aasen I (1997) *Mangelsjukdomar og andre ernæringsforstyrringar hos kulturplanter. Årsak – symptom – rådgjerer.* Landbruksforlaget, Oslo, Norway, 95 pp (in Norwegian)

Bouya D, Myttenaere C, Weissen F, Van Praag HJ (1999) Needle permea-

bility of Norway spruce (*Picea abies* (L.) Karst.) as influenced by magnesium nutrition. *Belgian Journal of Botany* **132 (2)**, 105-118

Butin H, Pehl L (1993) *Kabatina abietis* sp. nov., associated with browning of fir needles. *Mycological Research* **97**, 1340-1342

Chastagner GA, Byther R, Antonelli A, DeAngelis J, Landgren C (1997) *Christmas Tree Diseases, Insects, and Disorders in the Pacific Northwest: Identification and Management*, Washington State University, Cooperative Extension, 154 pp

Christensen CJ, Pedersen LB, Klarskov K (1997) *Nåleanalyser. Anvendelighed i vurderingen af bevoksningers næringsstofstatus samt som grundlag for gødningsanbefalinger.* Videnblade 5.9-7. 2 pp (in Danish)

Gadoury DM, Pearson RC, Riegel DG, Seem RC, Becker CM, Pscheidt JW (1994) Reduction of powdery mildew and other diseases by over-the trellis application of lime sulphur to dormant grapevines. *Plant Disease* **78**, 83-87

Kolling C, Pauli B, Haberle KH, Rehfuess KE (1997) Magnesium deficiency in young Norway spruce (*Picea abies* [L.] Karst.) trees induced by NH_4NO_3 application. *Plant and Soil* **195 (2)**, 283-291

Lange OL, Zellner H, Gebel J, Schramel P, Kostner B, Czygan FC (1987) Photosynthetic capacity, chloroplast pigments, and mineral content of the previous years spruce needles with and without the new flush – analysis of the forest decline phenomenon of needle bleaching. *Oecologia* **73**, 351-357

Lombnæs P, Singh BR (2003a) Effect of free manganese activity on yield and uptake of micronutrient cations by barley and oat grown in chelator-buffered nutrient solution. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* **53**, 161-167

Lombnæs P, Singh BR (2003b) Varietal tolerance to zinc deficiency in wheat and barley grown in chelator-buffered nutrient solution and its effect on uptake of Cu, Fe, and Mn. *Journal of Plant Nutrition and Soil Science* **166**, 76-83

Lombnæs P, Talgø V, Stensvand A (2008) Nordmann fir (*Abies nordmanniana*) grown in chelator-buffered nutrient solution with different combinations of calcium and magnesium. *Forest & Landscape Working Papers* **26**, 22-24

Lyhr KP (1994) *Håndbog til Identifikation af Skader på Nordmannsgran og Nobilis*, Dansk Skovforenings Pyntegrøntsektion, 98 pp (in Danish)

Marschner H (1995) *Mineral Nutrition of Higher Plants* (2nd Edn), Academic Press Ltd., London, UK, 889 pp

Mengel K, Kirkby EA (1987) *Principles of Plant Nutrition* (4th Edn), International Potash Institute, Bern, Switzerland

Parker DR, Chaney RL, Norvell WA (1995) Chemical equilibrium models: applications to plant nutrition research. In: Loeppert RH, Schwab AP, Goldberg SP (Eds) *Chemical Equilibrium and Reaction Models*, Special Publication No. 42, Soil Science Society of America, Madison, WIS, USA, pp 163-200

Pearson JN, Rengel Z (1994) Distribution and remobilisation of Zn and Mn during grain development in wheat. *Journal of Experimental Botany* **45**, 1829-1835

Pedler JF, Parker DR, Crowley DE (2000) Zinc deficiency-induced phytosiderophore release by the Triticaceae is not consistently expressed in solution culture. *Planta* **211**, 120-126

Perny B, Chech TH, Donaubauer E, Tomiczek CH (2002) *Krankheiten und Schädlinge in Christbaumkulturen*, Bundesamt und Forschungszentrum für Wald, Wien, Austria, 194 pp

Ravnsbæk PFV (1989) Nåleanalyser som middle til diagnosticering af næringsstofmangel i juletrækulturer af nordmannsgran, *Abies nordmanniana* (Stev.) Sparch. MS thesis, KVL, Copenhagen, Denmark, 100 pp (in Danish)

Rengel Z (1999) Physiological responses of wheat genotypes grown in chelator-buffered nutrient solutions with increasing concentrations of excess HEDTA. *Plant and Soil* **215**, 193-202

Ross IS (1975) Some effects of heavy metals on fungal cells. *Transactions of the British Mycological Society* **66**, 175-193

Singh BR, Steenberg K (1974) Plant response to micronutrients. II. Uptake, distribution and translocation of manganese in maize and barley plants. *Plant and Soil* **40**, 647-654

Talgø V, Cech T, Chastagner G, Thomsen IM, Riley K, Lange K, Stensvand A (2008) *Kabatina abietis* as a possible cause of current-season needle necrosis (CSNN) on fir. *Journal of Plant Pathology* **90 (2, Supplement)**, 94

Talgø V, Cech T, Stensvand A (2007) Fungi found in Norway and Austria in association with *Abies*-needles developing current season needle necrosis (CSNN). *Bioforsk Tema* 2 **(37)**, 5 pp. Available online: http://www.bioforsk.no

Talgø V, Chastagner G, Thomsen I, Cech T, Riley K, Lange K, Klemsdal S, Stensvand, A (2010) *Sydowia polyspora* associated with current season needle necrosis (CSNN) on true fir (*Abies* spp.). *Fungal Biology* **114 (7)**, 545-554

Talgø V, Stensvand A, Lombnæs P, Sæbø A (2005) Nutrient deficiencies in nordmann fir for Christmas tree production in Norway. In: *Program and Abstracts 7th International Christmas Tree Research and Extension Conference*, Tustin, Michigan 2–7 October 2005, 1 p

Thompson IA, Huber DM (2007) Manganese and plant diseases. In: Datnoff LE, Elmer WH, Huber DM (Eds) *Mineral Nutrition and Plant Diseases*, APS Press, USA, pp 139-153