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Fertilizing measures to decrease Norway spruce yellowing

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ABSTRACT: At the end of nineties, within the mountain forests of the Krušné hory Mts., in connection with an increased acid deposition, the symptoms (yellowing) started to be visible, characterizing magnesium deficiency in the assimilation organs, when Mg contents were laying under 300 mg/kg. In mineral soil the Mg content is mostly less than 10 mg/kg. Contents of other basic elements (Ca, K) were also very low. During four years yellowing symptoms of the spruce stands have developed in an extent area of more that 10,000 ha. Since 1999, preventive measures have been adopted to improve the nutrition status of the forest stands. Liquid magnesium fertilizers as MgNsol, Lamag Mg, MgSsol were applied during the period of 1999–2002. Since 2001, in semi-operational experiment, powder Mg fertilizer – Silvamix F4 – of higher Mg content (63.3% MgO) was applied. Application of liquid fertilizer MgNsol has helped to compensate the nitrogen deficiency in the stands of insufficient nutrition in this element. Comparing of different types of liquid fertilizers has confirmed, that the highest increase of magnesium in assimilation organs was find in combined application of MgNsol and MgSsol fertilizers. Application of 300 kg/ha Silvamix F4 has increased the magnesium content in the first needle year class in 73% in average, potassium in 33%, calcium in 16%, and phosphorus in 85%. Besides increased nutrient content in needles also improvement of the health and phosphorus in 85%. Besides increased nutrient content in needles also improvement of the health state, i.e. revitalization of the stands affected can be observed.

Keywords: Krušné hory Mts.; spruce stands; yellowing; Mg deficiency; Mg fertilizers; revitalization

In the Central and Western Europe, colour changes of needles (yellowing) of the spruce stands, caused by nutrition disturbance of characteristic magnesium insufficiency in the assimilation organs, were observed already in seventies and eighties of the last century. This insufficiency was connected with low contents of calcium, zinc and nitrogen. The symptoms, called "new forest damage" were find mainly in regions of high input of acid deposition, in soils of high acidity, of critically low content of basic elements, mainly magnesium. In most of the problem regions in Europe, the magnesium insufficiency was compensated by the application of liquid or powder fertilizers containing magnesium (Bonneau et al. 1990; Hüttl, Schaaf 1997; Hüttl 1989, 1990, 1993; Kaupenjohann 1997). During the eighties, individual trees or groups of trees of similar symptoms could be find also in CR. Only at the end of nineties, mainly after winter 1998/1999, area development of the symptom was observed, and during the following period yellowing of the spruce stands was graduating. Extent yellowing of the spruce stands of all age classes was developing in the western part of the Krušné hory Mts. (up to 8,000 ha), big groups of yellow trees were find also in the eastern part of the Krušné hory Mts. (Šrámek et al. 2001). Latter on, yellowing was observed in the Jizerské and Lužické Mts. and in Jeseníky. In 1999 already, the Forests of the Czech Republic, state enterprise, have applied liquid fertilizers in the most affected regions. Semi-field experiment with fertilizing was another step how to improve disturbed magnesium nutrition of the spruce stands. This was initiated by the Government Decision No. 532 of 2000, assigning the Ministry of Agriculture of the Czech Republic to adopt measures necessary to stop the risk of mass decline of forest in the Krušné hory Mts. and Orlické Mts. The aim of the contribution is to bring a short information on fertilizing in 1999–2003, and to present some partial results of application of liquid and powder fertilizers.

MATERIAL AND METHODS

Selecting the plots suitable for fertilizing

Selecting of the concrete localities, suitable for fertilizing, was done by the forest owners, on the base of visual symptoms, characterizing disturbed nutrition, typology and pedology characteristics, and the results of chemical analyses of humus, mineral soil and assimilation organs of the tree species. The proposals by the owner are to be consulted with the Institute of Forest Management (Ústav pro hospodářskou úpravu lesů), and to be agreed by the organs on nature protection. Selection of the type of fertilizer, manner and term of application were recommended by the Forest and Game Management Research Institute in Jíloviště-Strnady.

Sample taking and analyses of the assimilation organs and soil samples

Mixed samples of the first and second needle year class of ten individuals were taken in selected stands, in two terms – before the treatment and start of flushing, and in autumn, in dormancy period. Needle samples were taken in the upper third of the tree, exposed to the sunshine, optimally of the fourth whorl. Needle analysis was done in the laboratory of Forestry and Game Management Research Institute (FGMRI), using the valid methods by ICP Forest (UN-ECE Manual ICP 1998).

Samples of humus and mineral soil were taken in three spots, in each stand evaluated. Mineral soil was taken in the depth of 30 cm, characterizing possibilities of the spruce nutrition. Samples of humus and mineral soil were analyzed in the laboratory of FGMRI. Content of nutrients available was stated in the elution of NH_4Cl, total nutrient content in elution by aqua regia.

Application of fertilizers in individual years

In the western part of the Krušné hory Mts., within the plots where area yellowing of the stands was observed, liquid fertilizers were applied at 168 ha by the Forests of the Czech Republic, state enterprise, in 1999 (Šebková et al. 2001). Fertilizers MgN sol and Lamag Mo were applied in tree repetitions (total dose of 447 kg/ha MgNsol and 450 kg/ha Lamag Mo). Liquid fertilizer used, MgNsol, contained 10% MgO, 8% N, liquid fertilizer Lamag Mo 16% MgO.

In 2000, when the Government Decision No. 532 was adopted, with the aim to prepare the proposal on complex and systematic solution, how to stop degradation of forest soils under the air pollution load, application of fertilizers was supported also by the state financial sources. Liquid fertilizers with magnesium were applied also in Orlické Mts., at the area of about 170 ha, and in the Krušné hory Mts., at the area of 523 ha. Also in this year MgNsol (of total dose of 480 kg/ha) and Lamag Mo in three repetitions was used.

In 2001, within the stands affected in Krušné hory Mts., liquid Mg-fertilizers were applied (MgNsol – of total dose 300 kg/ha and Lamag Mo) at about 1,774 ha. In the western part of the Krušné hory Mts., in frame of the semi-field experiment, a special, slowly solving powder fertilizer, not containing chlorides, was used to treat the deficit stands. It was Silvamix F4 (total dose applied of 300 kg/ha) of higher magnesium content – 59% MgO, and low nitrogen content – 6%. The fertilizer also contained 5.9% of P_2O_5 and 4.2% of K_2O. This fertilizer was applied in the spruce stands of the area about 466 ha.

In 2002, in the Krušné hory Mts., at the area of about 794 ha, different types of liquid magnesium fertilizers were compared, in frame of the semi-field experiment organized by the Forests of the Czech Republic, state enterprise – MgNsol (300 kg/ha), MgSsol (375 kg/ha), and its combination with MgNsol. Liquid fertilizer applied, MgSsol, contains 9% of MgO.

With the support by the Ministry of Agriculture of the Czech Republic, within the semi-field experiment, powder magnesium fertilizer Silvamix F4, not containing nitrogen, was applied at 724 ha. Also in Orlické Mts., of high nitrogen deposition, where nitrogen/magnesium ratio started to be disturbed, a special, slowly solving fertilizer, not containing nitrogen, of higher potassium content (20% K_2O), Silvamix K3, was applied. Fertilizer also contains 10.6% MgO and 6.5% P_2O_5. Application was done at 193 ha.

In 2003, with the financial support by the Ministry of Agriculture, application of powder, slowly solving magnesium fertilizer, not containing nitrogen, Silvamix F4, was done both in the western and eastern part of the Krušné hory Mts. Spruce stands of the total area of 675 ha were fertilized from the air, another fertilizing was realized within the Forest District Lanškroun, at 500 ha.

RESULTS AND DISCUSSION

Semi-field experiments on fertilizing are still ongoing, they were not closed yet, so only the preliminary results of the application of Silvamix F4 can be presented, and comparing to the application of liquid fertilizer MgNsol. Further also compared results on liquid magnesium fertilizer will be presented.

Table 1. Relative representation of the soil samples in individual pH (KCl) groups, and individual classes of magnesium content

	pH (KCl)			
Relative number	2.5–3.0	3.1–3.5	3.6–4.0	4.1–4.5
(%)	24	56	11	9
	Mg content in soil samples (mg/kg)			
	0–10	11–21	21–++	
(%)	50	43	7	

Fertilizer has been applied in the stands growing on acid soils of significant insufficiency of basic elements in mineral layer.

The region of western Krušné hory Mts. can be well characterized by the results of investigation before application of lime and fertilizers, when samples of needles, humus, and upper soil horizons were taken and analyzed. Significant insufficiency of basic nutrients, mainly magnesium and calcium, was find both in needles and mineral soil. Extreme to strong acidity was proved at 80% of the soil samples taken. The pH value in KCl did not exceed 3.5 (Table 1). In a half of the mineral sol samples taken magnesium content was ranging within the interval of 0–10 mg/kg.

Nutrient contents in needles (Table 2), mainly magnesium, nitrogen, zinc, were deeply bellow the level of nutrient insufficiency. Mainly in older needle year classes they were so low, that the physiological processes were disturbed, resulting in irreversible damage of assimilation organs and their fall-down.

Effect of Silvamix F4 on magnesium content in assimilation organs

Specially prepared powder fertilizer of long-term effect was applied in frame of the semi-field experiment, the results will be evaluated latter this year. The experiment is realized within the Forest District Kraslice, in six fertilized and five control stands. Fertilizer was applied at the beginning of the vegetation season, in dose of 300 kg/ha. Samples of needles, humus, and mineral soil were taken before fertilizing. In autumn, after fertilizing, only needle samples were taken. The results on magnesium content in individual samples are presented in Fig. 1.

The results confirm low content of magnesium in mineral soil, and in the first and second needle year class. In needles it was mostly under the level of insufficiency, however, the term of sample taking (before flushing) has to be considered. Application of Silvamix F4 resulted in autumn already in increased magnesium content in the two needle year classes. First needle year class has reacted more significantly than the second. Magnesium content in the first needle year class has increased in average in 44%, in the second needle year class in 13%, compared to control. In MgNsol application, an increase in the first needle year class was 2%, compared to control, in the second needle year class even decrease of Mg content in 22%, compared to control, was recorded (see Fig. 2).

Considering a complex character of the Silvamix F4 fertilizer used (it contains also some other elements of mineral nutrition), also the content of basic elements was affected by the application. Comparatively low contents of calcium in mineral soil were not reflected in the calcium content in needles, this was sufficient in the two needle year classes analyzed, and it was increased slightly after the fertilizer was applied. In average it was an increase in 16 and 33% respective, in the first and second needle year class. Similar increase in the two needle year classes was observed also with potassium content, in 33% and 11% respective. Fertilizer applied has affected positively also phosphorus content, both in the first and second needle year class. Average increase in 85% in the first, and 60 % in the second needle year classed was recorded. In contrary, with the other elements evaluated – nitrogen, zinc and manganese, the change was minimal. The contents of these elements remained practically at the same level, or they were slightly increased. Sulphur was

Table 2. Average element content in the first to third needle-year class of Norway spruce

Needle-year class	N (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg	Zn (mg/kg)	S (mg/kg)	F (mg/kg)
I	1.08	1,179	4,763	1,823	357	18.4	988	2.13
II	1.07	1,112	4,538	2,785	299	16.7	1,125	2.60
III	1.02	1,268	4,900	2,079	219	12.6	1,248	2.41

Needle-year class: I – current year needles, II – one year old needles, III – two years old needles

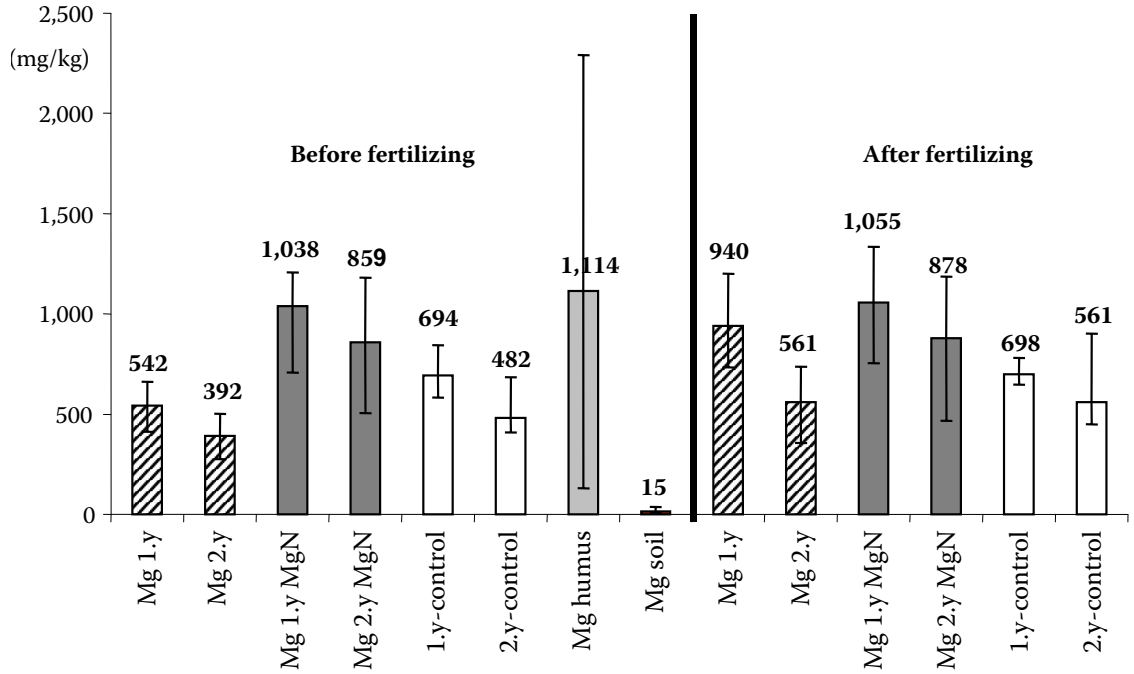

Fig. 1. Content of Mg in the 1st and 2nd needle year class before and after fertilizing, and Mg content in humus and soil before fertilizing for Silvamix F4 (Mg) and MgNsol (MgN)

cumulated in the two needle year classes, in autumn sampling higher sulphur contents, characterizing slight load of the region by sulphur emission, were recorded.

In conclusion it can be stated, that the partial results of the semi-field experiment show increased content of basic elements in needles, mainly of magnesium. Also visual evaluation of the stand proved better health state after the application of powder fertilizer Silvamix F4. Long-term effect of the fertilizer and state of soil will be evaluated in the next period.

Effect of the liquid fertilizers applied

In 2002 an aerial application of liquid magnesium fertilizers was done within the yellowing stands of the Western and Central Krušné hory Mts., of the total area of 793.96 ha. The MgNsol (100 kg of fertilizer in 250 l of water, in three terms) was used, and, for the first time, also MgSsol fertilizers, not containing nitrogen, and their combinations (125 kg of fertilizer in 250 l of water – in three terms). In FGMRI, to control the effect, samples were taken and analyzed in the stands treated, before and after the application.

Magnesium contents find in the first and second needle year class, before and after the application of fertilizer, are presented in Fig. 3 and 3a. In control localities, inter-year increase of magnesium in 18.4% was find, it was 12.2% in the first needle year class, and in 26.7% in the second. In the samples evaluated, the contents in second needle year classes were under the deficiency level. An increase of nutrient content in the control localities can be explained by optimal development of meteorological condi-

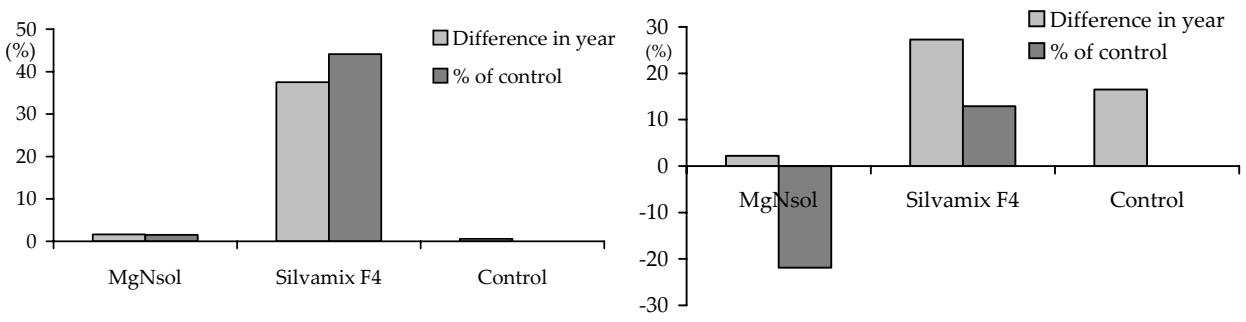

Fig. 2. Changes in Mg content in the 1st and 2nd needle year class, compared to control

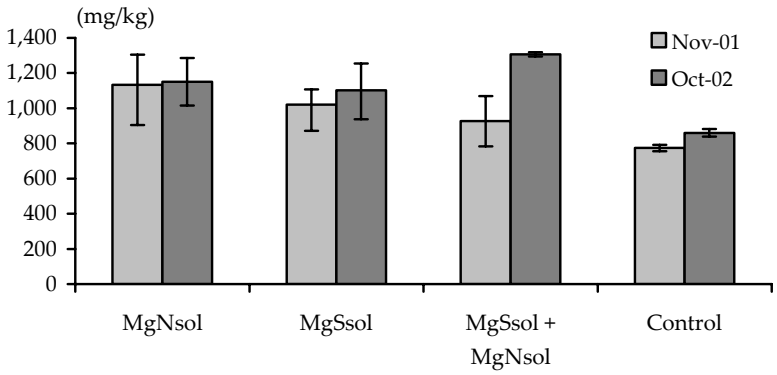

Fig. 3. Development of magnesium content according to the different types of application, in the 1st needle year class

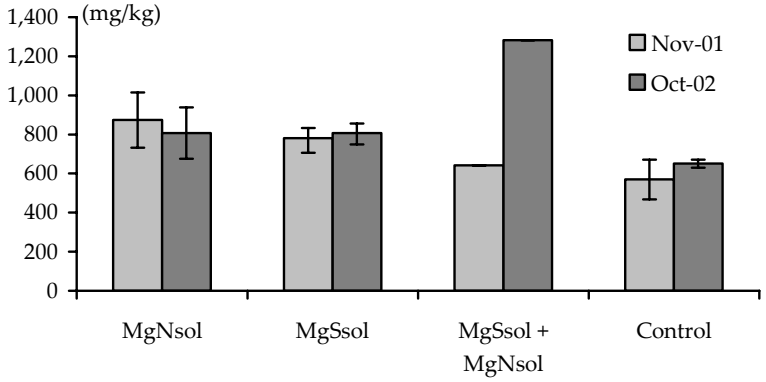

Fig. 3a. Development of magnesium content according to the different types of application, in the 2nd needle year class

tions during the vegetation season of 2002, making possible to use the nutrients available in the soil in optimal way.

For MgNsol the highest increments of magnesium content were find in combination with MgSsol – in 41% in the first, and in 100% in the second needle year class (see Figs. 4 and 5). The second needle year class has shifted from deficiency level to very good magnesium supply (Fig. 6). Compared to the control, results in 2002 show significant increase of Mg content, up to 46% in the first needle year class, and in 72.2% in the second.

In the application of pure MgNsol, slight increase of magnesium in the first needle year class was recorded, in 1.6%, in the second needle year slight inter-year decrease was observed. Compared to the control, magnesium content has increased in 33 and 24% respective, in the first and second needle year class, which means a shift of the content at the border of deficiency level to good magnesium supply.

For MgSsol in the first needle year class the inter-year increase was nearly 5%, in the second even decrease in 3.3% was recorded. Compared to the control, magnesium content in the first needle year class has increased in 11.3%, in the second only in 1.6%. Total increase in absolute values is negligible, considering the development in the control plots, the impact of fertilizer was insignificant. It has to be

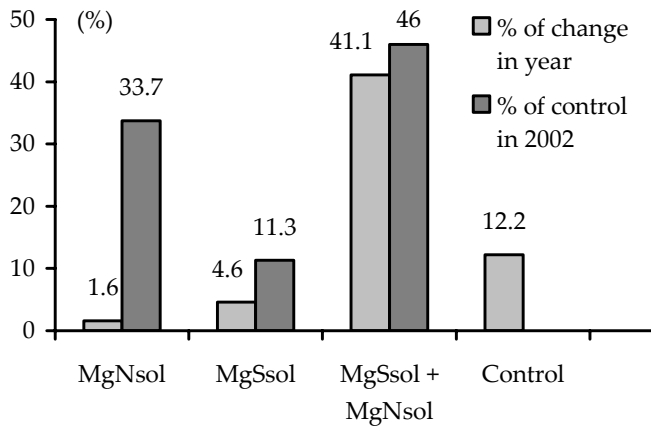

Fig. 4. Relative changes of Mg content among individual years, and in relation to the control – 1st needle year class

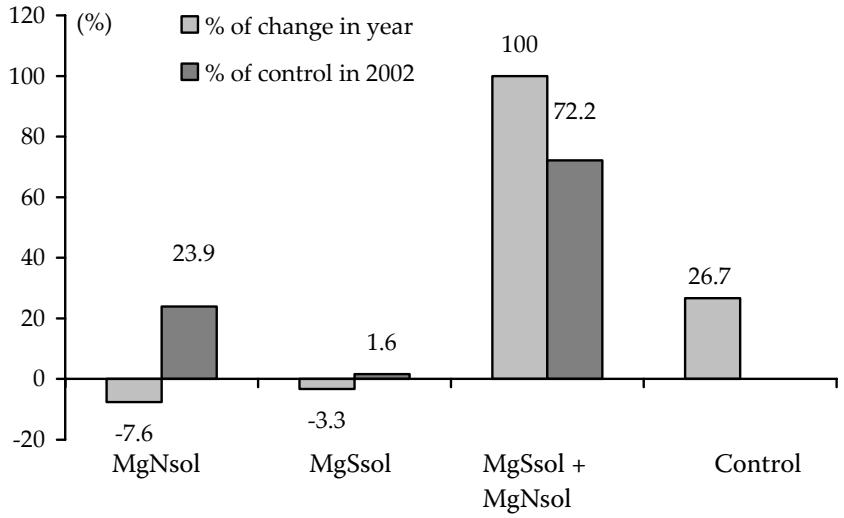

Fig. 5. Relative changes of Mg content among individual years, and in relation to the control – 2nd needle year class

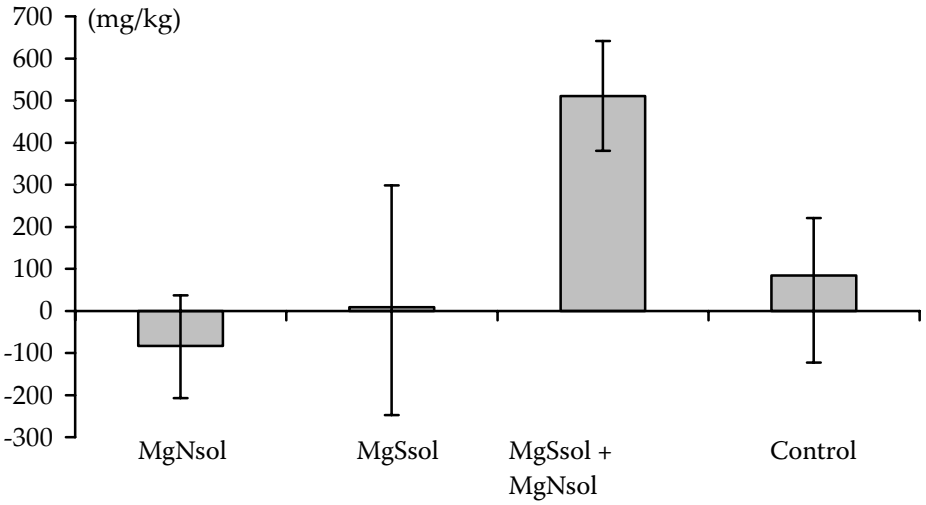

Fig. 6. Changes of Mg content in the period of November 2001 and October 2002 – 1st and 2nd needle year classes

presented, that the starting values for magnesium in the localities investigated were comparatively high (same as with the application of pure MgNsol), not any sample was under deficiency level.

From the viewpoint of nutrition problems, it can be stated, that in the control localities 2 samples were under the deficiency level for magnesium, in November 2001, in May 2002 there were 3 such samples, in October 2002 again 2 samples. Within the localities fertilized, 3 samples were deficient in Mg in November 2001, 5 in May 2002, and only 1 sample in October 2002, after the application of liquid fertilizers.

CONCLUSION

– Significant magnesium deficit in needles (Mg contents under 500 mg/kg), resulting in yellowing of the spruce stands in poor, acid soils, in the regions of high acid deposition, can be successfully compensated by the application of complex powder fertilizers of higher magnesium content, and application of liquid fertilizers. Under the conditions of today, relatively high, nitrogen inputs into the ecosystem, fertilizers not containing nitrogen are to be preferred.

– Application of 300 kg/ha of the complex, slowly solving fertilizer Silvamix F4 has increased the content of magnesium in the first needle year class in average up to 73%, potassium content in 33%, calcium in 16%, and phosphorus in 85%. Besides increased nutrient content in needles, an improved health state of the stands, i.e. revitalization, can be observed.

– Application of the liquid fertilizer MgNsol has improved the state of the stands with magnesium

deficiency, it has helped also to cope with nitrogen deficiency. However, the only significant increase of magnesium content in assimilation organs was observed in combination of the fertilizers MgNsol and MgSsol.

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Hnojení jako opatření ke snížení žloutnutí porostů smrku ztepilého

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ABSTRAKT: Na konci devadesátých let se v horských lesích Krušných hor zároveň se zvyšující se kyselou depozicí objevily viditelné symptomy (žloutnutí), charakterizující nedostatek hořčíku v asimilačních orgánech; obsah hořčíku se dostal pod hranici 300 mg/kg. V minerální půdě byl obsah hořčíku nižší než 10 mg/kg. Obsahy dalších bazických prvků (Ca, K) byly take velmi nízké. Během čtyř let se žloutnutí smrkových porostů rozšířilo na více než 10 000 ha. Od roku 1999 byla přijata preventivní opatření na zlepšení výživy lesních porostů. V období let 1999–2002 byla aplikována kapalná hořečnatá hnojiva jako MgNsol, Lamag Mg a MgSsol. Od roku 2001 se v poloprovozním pokusu používá práškové hořečnaté hnojivo – Silvamix F4 – s vyšším obsahem hořčíku (63,3 %). Aplikace kapalného hnojiva MgNsol kompenzovala nedostatek dusíku v porostech nedostatečně vyživovaných tímto prvkem. Při srovnávání různých druhů kapalných hnojiv se potvrdilo, že nejvyšší obsah hořčíku v asimilačních orgánech lze pozorovat při kombinaci hnojiv MgNsol a MgSsol. Aplikace 300 kg/ha hnojiva Silvamix F4 zvýšila obsah hořčíku v prvním ročníku jehličí v průměru o 73 %, obsah draslíku o 33 %, vápníku o 16 % a fosforu o 85 %. Kromě zvýšení obsahu živin v jehličí bylo možné pozorovat take zlepšení zdravotního stavu, tj. revitalizaci postižených porostů.

Klíčová slova: Krušné hory; smrkové porosty; žloutnutí; nedostatek hořčíku; hořečnatá hnojiva; revitalizace

Na konci devadesátých let se v horských lesích Krušných hor, zároveň se zvyšující se kyselou depozicí, objevily viditelné symptomy (žloutnutí), charakterizující nedostatek hořčíku v asimilačních orgánech; obsah hořčíku v jehličí se dostal i pod 300 mg/kg. V minerální půdě byl obsah hořčíku nižší než 10 mg/kg. Obsahy dalších bazických prvků (Ca, K) byly také velmi nízké. Během čtyř let se žloutnutí smrkových porostů rozšířilo na více než 10 000 ha. Od roku 1999 byla přijata preventivní opatření na zlepšení výživy lesních porostů. V období let 1999–2002 byla aplikována kapalná hořečnatá hnojiva jako MgNsol, Lamag Mg, MgSsol. Od roku 2001 se v poloprovozním pokusu používá

práškové hořečnaté hnojivo Silvamix F4 s vyšším obsahem hořčíku (63,3 %). Po přijetí vládního usnesení č. 532, které dalo za úkol připravit návrh komplexního a systémového řešení zastavení degradace lesních půd vlivem imisí, byla aplikace hnojiv od roku 2000 podpořena i ze státních zdrojů.

Směsné vzorky jehličí se odebíraly pro první a druhý ročník jehličí vždy z deseti jedinců smrku ztepilého v termínech vždy na podzim před zásahem a po provedené aplikaci hnojiva v době vegetačního klidu. Analýza jehličí se prováděla ve zkušebních laboratořích Výzkumného ústavu lesního hospodářství a myslivosti podle platných metodik ICP Forests (UN-ECE Manuál ICP 1998). Vzorky humusu a minerální půdy se odebíraly ze tří míst v každém hodnoceném porostu. Minerální půda se odebírala do hloubky 30 cm, která vhodně charakterizuje možnosti výživy smrkových porostů. Obsah přístupných živin byl stanoven ve výluhu NH_4Cl, obsah celkových živin ve výluhu lučavkou královskou. Poloprovozní pokusy s hnojením stále probíhají, proto jsou prezentovány jen částečné výsledky poloprovozní aplikace komplexního hořečnatého bezdusíkatého hnojiva Silvamix F4 a jeho porovnání s aplikací tekutého hnojiva MgNsol (rok 2001) a výsledky porovnání tekutých hořečnatých hnojiv MgNsol a MgSsol a jejich kombinace, provedené v roce 2002.

Z výsledků bylo patrné, že letecká aplikace kapalného hnojiva MgNsol provedená v roce 2001 mírně kompenzovala nedostatek hořčíku v jehličí, ale také nedostatek dusíku v porostech, kde byla zjištěna nedostatečná výživa tímto prvkem.

Aplikace 300 kg/ha pomalu rozpustného komplexního hořečnatého bezdusíkatého hnojiva Silvamix F4 zvýšila obsah hořčíku v prvním ročníku jehličí mezi oběma odběry v průměru o 73 %, ve srovnání s kontrolní variantou pak až o 44 %. Zvýšil se obsah i dalších prvků – draslíku o 33 %, vápníku o 16 % a fosforu o 85 %. Kromě zvýšení obsahu živin v jehličí bylo možné pozorovat také zlepšení zdravotního stavu, tj. revitalizaci postižených porostů.

Při srovnávání různých druhů kapalných hnojiv v roce 2002 se potvrdilo, že nejvyšší zjištěný obsah hořčíku v asimilačních orgánech a největší statisticky významné změny v obsahu hořčíku během roku bylo možné pozorovat u varianty s kombinací hnojiv MgNsol a MgSsol. Obsah hořčíku vzrostl o 41 % u prvního a o 100 % u druhého ročníku jehličí. Ve druhém ročníku jehličí se obsah Mg posunul z oblasti deficience do oblasti velmi dobré výživy. Srovnání s kontrolou v roce 2002 ukazuje na výrazné navýšení obsahu Mg až o 46 % v prvním ročníku jehličí a o 72,2 % v druhém ročníku jehličí.

Z provedeného hodnocení poloprovozního pokusu s hnojením deficitních smrkových porostů vyplynuly následující závěry.

– Narušenou rovnováhu výživy a výrazný deficit obsahu hořčíku v jehličí charakterizovaný obsahy nižšími než 500 mg/kg, který se projevuje žloutnutím jehličí smrkových porostů zvláště na chudých a kyselých půdách v oblastech s vysokou kyselou depozicí (Krušné a Orlické hory), lze úspěšně upravit aplikací sypkých komplexních hnojiv s vyšším obsahem hořčíku nebo včasnou aplikací tekutých hořečnatých hnojiv.

Při současných relativně vysokých vstupech dusíku do ekosystému je třeba preferovat hnojiva neobsahující dusík.

Aplikace komplexního pomalu rozpustného hořečnatého hnojiva Silvamix F4 navýšila obsah hořčíku v prvním ročníku jehličí v průměru až o 44 % ve srovnání s kontrolou. Tekutá hořečnatá hnojiva, zvláště kombinace hnojiv MgNsol a MgSsol, také o 46 % navýšila obsah hořčíku u prvního ročníku jehličí. Kromě zvýšení obsahu hořčíku v jehličí bylo možné v ošetřených porostech pozorovat i zlepšení zdravotního stavu.

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