

## Effect of Mg fertilization on yellowing disease of Norway spruce at higher elevations of the Šumava Mts., Czech Republic

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**ABSTRACT:** Norway spruce yellowing and defoliation caused by Mg deficiency was frequently recorded on many sites of the Šumava Mts. (Bohemian Forest Mts.) since 1980's. A forest experiment aimed at investigation response of spruce to Mg application (commercial fertilizer SILVAMIX® Mg NPK) was set up in 1998. Fertilizer was applied manually in a dose of 96.5 kg Mg/ha in spruce (S) and beech-spruce (BS) vegetation altitudinal zones in spring 2000. Immediate decrease of yellowing was revealed in fertilized plots in both vegetation zones and yellowing almost completely disappeared at the end of the investigation in 2005. Further, fertilization resulted in stabile foliation while marked defoliation was reported from control plots in both vegetation zones. Mg deficiency can be effectively eliminated by appropriate fertilizer application. Balanced nutrition contributes to long-term vigour and stability of forest stands.

**Keywords:** Mg deficiency; defoliation; long-term effect; Bohemian Forest Mts.; needle yellowing

Yellowing of Norway spruce is a new type of disease that has been frequently reported from many European mountains in altitudes over 700 m a.s.l. since the beginning of 1980s (DREYER et al. 1994; SIEFERMANN-HARMS et al. 2004; PODRÁZSKÝ 2006). Limited Mg availability causing strong Mg deficit in plant tissues is a generally accepted cause of this disease (ZIMMERMANN et al. 1988). In many regions of Central Europe, Mg deficiency in forest soils and consequently in assimilatory organs is commonly ascribed to acid depositions promoting intensive leaching of bases, imbalance of nutrients and release of toxic aluminum decreasing root absorption of the scarce Mg ions (KOLLING et al. 1997).

Yellowing starting from needle-tip and following shedding of older foliage with the youngest shoots remaining green are characteristic symptoms of Mg deficiency. This type of yellowing was recorded on spruce from seedlings to mature trees and can be experimentally induced by plantation of seedlings

in soils from mature stands where yellowing was recorded or by excessive fertilization by nitrogen in Mg limited conditions (NECHWATAL, OBWALD 2003). In nature forests, declining individuals with yellow needles are frequently growing in close vicinity of fully green healthy trees (KANDLER, MILLER 1990). NECHWATAL and OBWALD (2003) reported that green trees showed much better Mg nutrition than yellow trees although they were growing on the same substrate. Needle yellowing is according to their results at least partly mediated by fine root and mycorrhize disorders caused by adverse soil conditions. Further yellowing disease can be accelerated if Mg deficiency is coinciding together with other stress factors such as ozone pollution (SIEFERMANN-HARMS et al. 2005), excessive exposure to sun light (BOXLER-BALDOMA et al. 2006) or drought during the growing season (DAMBRINE et al. 1993; SOLBERG 2004).

In the Czech Republic and its close neighborhood, yellowing had been documented especially from

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Fig. 1. Position of a study site is indicated by a circle

mountain ranges located along the borderland with Austria and Germany since mid 1980s, particularly in Šumava Mts. (Bohemian Forest Mts.) and Krušné hory Mts. (Ore Mts.) (KATZENSTEINER et al. 1992a; PODRÁZSKÝ et al. 2003; LOMSKÝ et al. 2006). These regions are characterized by poor acid soils with low content of basic nutrients, magnesium primarily, and by relatively high acid deposition (LOMSKÝ et al. 2002). Yellowing can result in “new type of forest decline” even in altitudes where Norway spruce was autochthonous dominant of virgin forests and where the last primary spruce stands still remain. To improve stands vitality and prevent from forest decline, fertilization leading to elimination of Mg deficiency is generally recommended treatment (JANDL et al. 2001; KATZENSTEINER et al. 1992b; KOLLING et al. 1997; LOMSKÝ et al. 2006; MOHAMED et al. 1993). Studies evaluating experimentally long-term after effect of fertilization on spruce recovery from yellowing in various soil and climatic conditions are still rare. With regard to this fact, the aim of this study was to investigate long-term effect of

SILVAMIX Mg fertilizer application on needle yellowing and foliation of spruce stands affected by Mg deficiency.

## MATERIALS AND METHODS

This study was performed in the Šumava Mts. (Bohemian Forest Mts.) a chain of middle mountains on the borderland between the Czech Republic, Austria and Germany (48°49'31.33''N, 13°50'10.89''E beech-spruce zone, 48°46'29.88''N, 13°50'28.03''E spruce zone, Fig. 1). The average annual precipitation in the area was 1,091 mm and the mean annual temperature was 4.2°C. Effect of fertilization on spruce recovery from yellowing was studied in two altitudinal zones: beech-spruce (BS) vegetation zone in altitude of 920 m and spruce (S) vegetation zone in 1,230 m a.s.l. Stand age was 44 and 107 years in BS and S zones, respectively. Spruce yellowing had been regularly observed in the selected plots several years before establishing of the experiment but not reached critical extend leading to forest decline. In each zone, pair of neighboring 50 × 50 m plots was selected in 1998 with respect to their maximal homogeneity in spruce yellowing symptoms, stand characteristics and environmental conditions as well. One plot was control (C treatment) without any experimental manipulation and fertilizer in the dose of 96.5 kg Mg/ha was applied into the second plot in each zone in spring 2000 (F treatment). Slow-release fertilizer with commercial name SILVAMIX<sup>®</sup> Mg NPK was used and is described in detail in Table 1. N, P and K were nutrients applied together with Mg.

Yellowing was estimated visually as a percentage of yellow needles on each investigated tree and foliation

Table 1. Chemical composition of slow-release fertilizer with commercial name SILVAMIX<sup>®</sup> Mg NPK used in the experiment

Composition	%
<b>Nitrogen total (N)</b>	<b>10.0</b>
Nitrogen from urea formaldehyde (N):	6.0
– that is soluble in cold water (N)	1.6
– that is only soluble in hot water (N)	2.7
– that is insoluble in hot water (N)	1.7
– that is insoluble in cold water (N)	4.4
Ureic nitrogen [CO(NH <sub>2</sub> ) <sub>2</sub> ]	4.0
<b>Phosphorus soluble in neutral ammonium citrate and in water (P<sub>2</sub>O<sub>5</sub>)</b>	<b>13.0</b>
Water soluble phosphorus (P <sub>2</sub> O <sub>5</sub> )	12.0
<b>Water soluble potassium (K<sub>2</sub>O)</b>	<b>6.5</b>
Magnesium total (MgO)	16.0
Sulphur (S)	0.4

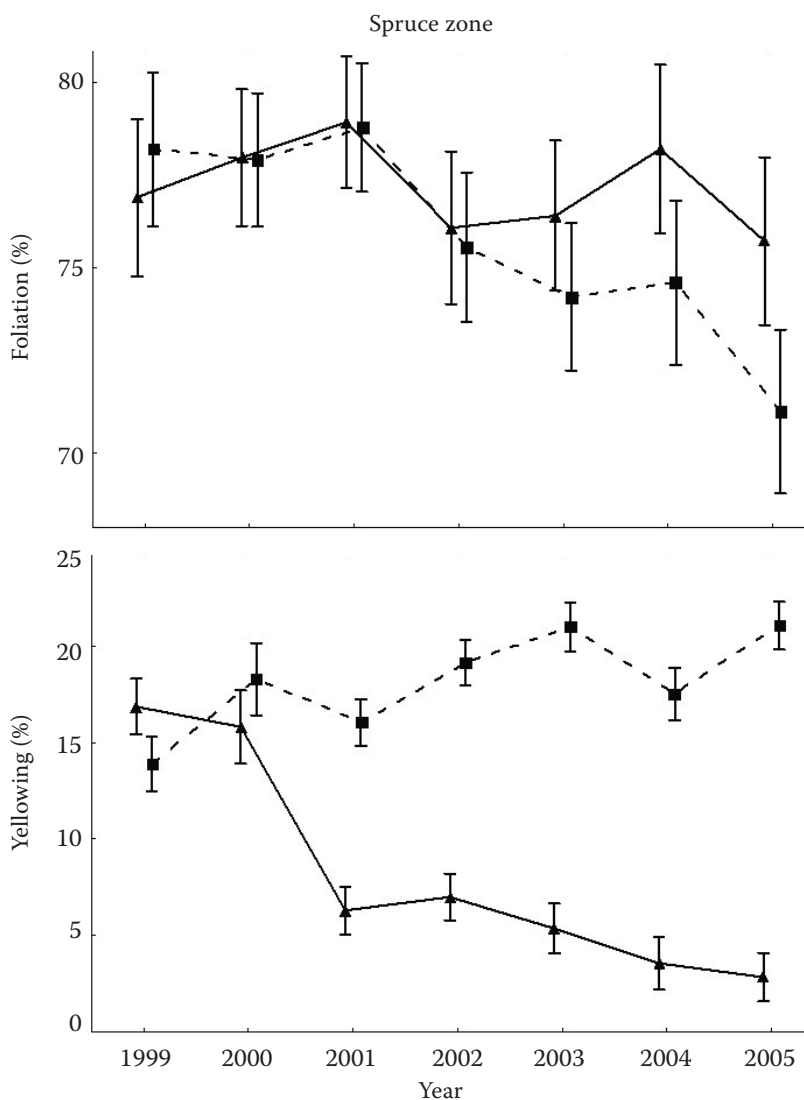


Fig. 2. Percentage of Norway spruce foliation and yellowing in a spruce vegetation zone. Error bars indicate 95% confidence interval. C and F treatments are indicated by squares and triangles respectively (solid line – F treatment, broken line – C treatment)

as a percentage of remaining needles from supposed amount on healthy tree in each autumn from 1999 to 2005.

tilized plots indicating diversification of estimated parameters and long term after-effect of performed fertilization.

#### Data analysis

Repeated measures ANOVA in STATISTICA 5.0 software (StatSoft 1995) was used to evaluate yellowing and foliation of spruce because the data were collected in the form of repeated observations of individual trees with the baseline data recorded before the first experimental manipulation. Three effects were analyzed: treatment, time and treatment  $\times$  time interaction. Significant effect of treatment indicates differences between plots but says nothing about temporal development of these differences. Significant effect of time indicates variation of investigated parameter by reason of year to year variability. Treatment  $\times$  time interaction is the most interesting effect. If significant, there is a non-parallel temporal development of control and fer-

#### RESULTS

##### Spruce zone

313 living trees were monitored in both treatments in spruce vegetation zone: 160 in C and 153 in F treatment. To eliminate zero values from the calculation, trees died during the experimental period were removed from all analyses. The main cause of tree dying was attack by bark beetle namely in F treatment located close to edge of the stand where the attack started. Totally 10 and 20 trees died in C and F treatment during the study period. Although the foliation was lower in F than in C treatment in 1999 and F treatment was more attacked by bark beetle, percentage of foliation remained in both treatments on the same level in 2000 and 2001. Further folia-

tion was higher in F than in C treatment from 2001 onwards to the end of data collection in 2005 (Fig. 2). Mean percentage of foliation revealed before experimental manipulation was 78.2 and 76.9 in C and F treatments. In 2005, five years after fertilizer application, it was 71.1 and 75.7% in C and F treatments respectively. Non-significant effect of treatment indicated low differences between treatments in the initial phase of the experiment (Table 2). Significant effect of time revealed inter-annual variability and decreasing trend in foliation during the experimental period. Significant interaction of treatment and time showed increase in difference between treatments after fertilization. At the end of the experiment, well remarkable positive after-effect of fertilization on foliation of Norway spruce was documented.

Fertilization immediately affected percentage of yellow needles. Yellowing was moderately higher in F than in C treatment in baseline data, but reverse percentage of yellow needles was recorded from 2000 onwards (Fig. 2). In F treatment, continuous decrease

in percentage of yellow needles was recorded from 16.9 in 1999 to 2.8 in 2005. In C treatment, on the other hand, percentage of yellow needles increased from 13.9 in 1999 to 21.1 in 2005. All tested effects significantly affected yellowing (Table 2).

### Beech-spruce zone

206 living trees were monitored in beech-spruce vegetation zone: 126 in C and 80 in F treatment. Trees died during the run of the experiment were removed from the analysis. Number of trees died during the run of the experiment was 33 and 49 in C and F treatments, respectively. The main reason for trees dying was attack of bark beetle. In contrast to spruce vegetation zone, foliation was significantly affected by all tested effects – treatment, time and treatment  $\times$  time interaction as well (Table 2). Foliation was 88% in both treatments in baseline data collected in 1999 (Fig. 3). In 2000 and 2001, foliation was slightly higher in F than in C treatment. Steep

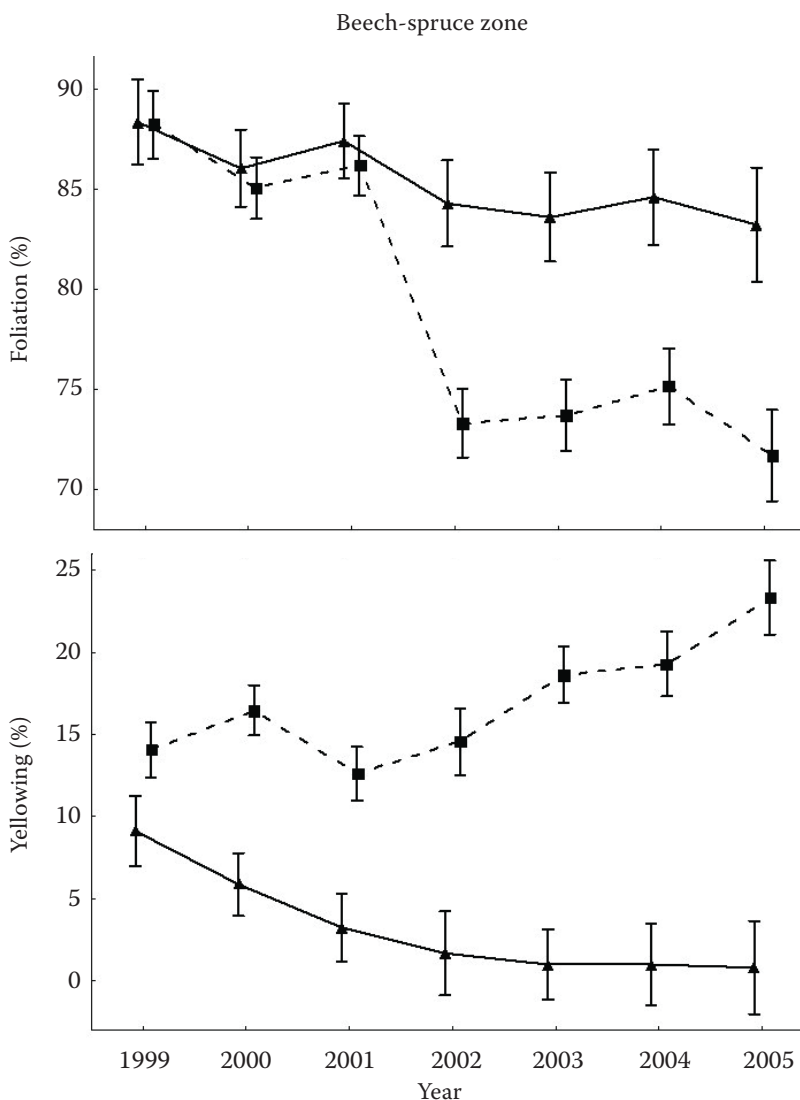


Fig. 3. Percentage of Norway spruce foliation and yellowing in a beech-spruce vegetation zone. Error bars indicate 95% confidence interval. C and F treatments are indicated by squares and triangles respectively (solid line – F treatment, broken line – C treatment)

Table 2. Results of repeated measurements ANOVA analyses of spruce foliation and yellowing in both investigated vegetation altitudinal zones

Vegetation zone	Variable	Effect	Degrees of freedom	<i>F</i> -ratio	<i>P</i> -value
Spruce	foliation	treatment	1	1.1	0.299
		time	6	35.7	< 0.001
		treatment × time	6	12.1	< 0.001
	yellowing	treatment	1	166.7	< 0.001
		time	6	44.4	< 0.001
		treatment × time	6	118.6	< 0.001
Beech-spruce	foliation	treatment	1	24.6	< 0.001
		time	6	143.7	< 0.001
		treatment × time	6	48.6	< 0.001
	yellowing	treatment	1	125.4	< 0.001
		time	6	12.0	< 0.001
		treatment × time	6	41.4	< 0.001

decrease of foliation was detected between years 2001 and 2002 in C treatment while moderate decrease was revealed in F treatment only. At the end of the experiment, foliation was 71.7 and 83.3% in C and F treatments, respectively.

Similarly as in the spruce vegetation zone, yellowing was immediately affected by fertilization (Fig. 3). While continuous decrease in percentage of yellow needles from 9.1 in 1999 to 0.8 in 2005 was revealed in F treatment, continuous increase, only with exception of a year 2001, was recorded in C treatment. Increase from 14.1% to 23.3% of yellow needles was detected from 1999 to 2005. All tested effects significantly affected yellowing (Table 1).

In both investigated altitudinal vegetation zones where Mg was deficient nutrient, fertilization positively affected tree foliation and decreased percentage of yellow needles as well.

## DISCUSSION

Although N, P, K and S were nutrients applied together with Mg in the form of commercial fertilizer, the development of foliation and yellowing was the most probably affected especially by Mg application, because symptoms of Mg deficiency were frequently recorded before fertilizer application in all plots and in controls during a run of the study.

Fertilization resulted relatively quickly in spruce recovery from yellowing and in longer time scale improved percentage of foliation as well. In control, on the contrary, continuous deterioration of foliation was revealed. Addition of deficient nutrient increased state of health of spruce stands in both

altitudinal vegetation zones. Positive influence of fertilization on vitality of spruce stands was the most clear after elimination effect of bark beetle attack starting from one side of the plot, not regularly in all plots, and causing thus noise in the data. Excluding trees died during the experimental period from calculation enabled therefore to remove substantial part of this noise and to show effect of fertilizer on trees vitality much clearly.

As is obvious from the comparison of fertilized and control plots, application of deficient nutrient, most probably Mg in the case of this study, substantially increased stability of spruce stand stressed by deteriorated soil conditions caused by acid deposition predominately. This conclusion is in accordance with experiments performed in other localities where Mg was revealed as deficient nutrient leading to needle yellowing and increasing thus risk of consequent forest decline (HUTTL, SCHNEIDER 1998; JANDL et al. 2002; KATZENSTEINER et al. 1992b; LOMSKÝ et al. 2006). Rate of stand response to Mg fertilization differed in relation to age and altitude of stand in our experiment, but both effects could not be evaluated separately because an age of stands was different in S and BS zones. Nevertheless higher rate of response to fertilizer application revealed in younger stand is in accordance with findings of PODRÁZSKÝ and VACEK (2005) indicating that the stand age is one from the main factors affecting effectiveness of fertilizer application. Further, lower foliation and higher share of needle yellowing revealed in higher elevation in this study is in accordance with results of KATZENSTEINER et al. (1992a) from neighboring locality in Bohemian Forest in Austria. Topography



showed significant effect on forest conditions: Needle loss, as a measure of the tree vigour and nutritional imbalances, especially Mg and Ca deficiency, was more severe in higher elevations and on west slopes which face the prevailing winds. It is obvious that both factors, stand age and altitude, were probably responsible for differences in initial foliation and response to fertilizer application in our study.

Apart from frequently recommended liming (KONÔPKA, PAVLENDÁ 2004), SILVAMIX® Mg NPK fertilizer can be used to effectively suppress symptoms of Mg deficiency. Effect of this fertilizer on yellowing and foliation was relatively long-term because differences between C and F treatments were still well visible six years after application. Positive effect of the fertilizer on stand nutrition and vitality can be probably ascribed to application of other nutrients as well. P and K are often limiting minerals in the Bohemian Forest Mts. (JANDL et al. 2001) therefore their application could contribute to improved trees nutrition and consequently vitality.

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## **Působení hořečnatých hnojiv na snížení žloutnutí smrku ztepilého ve vyšších nadmořských výškách na Šumavě, Česká republika**

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**ABSTRAKT:** Žloutnutí a defoliace smrkových porostů způsobené nedostatkem Mg byly opakovaně zaznamenávány na různých místech Šumavy od osmdesátých let minulého století. Experiment zaměřený na výzkum reakce smrku na aplikaci hořečnatého hnojiva (průmyslové hnojivo SILVAMIX® Mg NPK) byl založen v roce 1998. Hnojivo bylo aplikováno ručně v dávce 96,5 kg Mg/ha ve smrkovém a buk-smrkovém lesním vegetačním stupni na jaře roku 2000. Na hnojených plochách byl zaznamenán okamžitý pozitivní účinek aplikace, který se projevil snížením žloutnutí v obou lesních vegetačních stupních. Na konci období sledování v roce 2005 pak projevy žloutnutí smrku téměř kompletně zmizely. Kromě toho se hnojení projevilo také stabilizací olistění smrku, zatímco na kontrolních plochách byla v obou vegetačních stupních zaznamenána patrná defoliace. Deficit ve výživě smrkových porostů hořčíkem může být efektivně eliminován vhodnou aplikací hnojiv. Vyvážená výživa přispívá k dlouhodobé vitalitě a stabilitě lesních porostů.

**Klíčová slova:** deficit hořčíku; defoliace; dlouhodobý účinek; Šumava; žloutnutí jehlic

Žloutnutí smrku ztepilého jako nový typ poškození bylo opakovaně doloženo z řady evropských pohoří v nadmořských výškách nad 700 m již od počátku osmdesátých let minulého století (DREYER et al. 1994; SIEFERMANN-HARMS et al. 2004; PODRÁZSKÝ 2006). Omezené množství přístupného hořčíku, které způsobuje výrazný deficit tohoto prvku v rostlinných pletivech, je obecně považováno za hlavní příčinu tohoto poškození (ZIMMERMANN et al. 1988). Nedostatek hořčíku v půdě a následně i v asimilačním aparátu je běžně přičítán kyselé depozici spojené s vymýváním bází, nevyváženou výživou a mobilizací toxického hliníku, snižující absorpci iontů hořčíku kořeny smrku (KOLLING et al. 1997). V České republice a jejím okolí bylo žloutnutí lesních porostů doloženo především z horských oblastí podél hranice s Rakouskem a Německem (Šumava, Krušné hory). Tyto regiony se vyznačují chudými kyselými půdami s nízkým obsahem základních živin a relativně vysokou kyselou depozicí.

Hnojení aplikované dodáním deficitního hořčíku je obecně doporučované opatření pro zlepšení vitality porostů a zabránění jejich odumření (JANDL et al. 2001; KANZENSTEINER et al. 1992b; KOLLING et al. 1997; LOMSKÝ et al. 2006; MOHAMED et al. 1993). Studie hodnotící dlouhodobé efekty hnojení jsou však stále vzácné. Proto bylo cílem práce vyhodnotit dlouhodobý vliv aplikace hořečnatého hnojiva (SILVAMIX® Mg NPK) na žloutnutí a defoliaci smrkových porostů s výraznou deficiencí při výživě hořčíkem v oblasti Šumavy. V roce 1998 byly založeny dvě dvojice výzkumných ploch (50 × 50 m) v 7. a 8. lesním vegetačním stupni (920 a 1 230 m n. m.). Věk porostu byl 44 let (920 m n. m.) a 107 let (1 230 m n. m.). Jedna z ploch ve dvojici bylo ponechána bez zásahu (C) a na druhé byla na jaře roku 2000 provedena aplikace hnojiva SILVAMIX® Mg NPK v dávce 96,5 kg hořčíku na 1 ha (označena F). Žloutnutí bylo vizuálně hodnoceno jako procentuální podíl žlutých jehlic na všech stromech každo-

ročně na podzim (v letech 1999–2005). Stejně tak i olistění, které bylo stanoveno jako procentuální podíl jehlic z předpokládaného množství asimilačního aparátu zdravého stromu.

Opakované statistické hodnocení získaných údajů o žloutnutí a defoliaci bylo provedeno metodou analýzy rozptylu (ANOVA) v programu STATISTICA 5.0 (StatSoft 1995). Analyzovaly se tři faktory: opatření (hnojení), rok (čas) a opatření (hnojení) v interakci s časem. Průkazný vliv melioračního opatření indikuje rozdíly mezi plochami, ale neříká nic o časovém vývoji těchto rozdílů, průkazný vliv času indikuje proměnlivost zkoumaného parametru z důvodu meziroční variability. Interakce mezi melioračním opatřením a časem je nejvýznamnějším efektem. Je-li tento efekt statisticky průkazný, pak neexistuje paralela mezi časovým vývojem kontrolních ploch a ploch ošetřených aplikací hnojiv, což indikuje diverzifikaci zkoumaných parametrů a dlouhodobý efekt provedeného hnojení. Z prováděných statistických výpočtů byly vyřazeny stromy, které během sledovaného období odumřely. Hlavní příčinou mortality byl výrazný atak lýkožrouta smrkového.

Ve smrkovém lesním vegetačním stupni bylo olistění na počátku experimentu (1999) větší na kontrolní ploše ve srovnání s plochou, na které bylo v roce 2000 provedeno hnojení (na ploše F 76,9 %, na ploše C 78,2 %). V letech 2000 a 2001 zůstalo olistění na obou plochách srovnatelné. Po roce 2001 se již projevil pozitivní vliv hnojení, který zvýšil olistění hnojené plochy. Tento trend byl zjevný až do konce sledovaného období v roce 2005 (71,1 % na ploše C a 75,7 % na ploše F). Byl zjištěn statisticky průkazný vliv interakce mezi provedeným melioračním opatřením a časovým vývo-

jem, což se projevilo nárůstem rozdílů mezi variantami po provedeném přihnojení. Hnojení také okamžitě pozitivně ovlivnilo žloutnutí smrku. To bylo na počátku pokusu o něco vyšší na ploše F (16,9 %) než na ploše C (13,9 %). Obrát byl zaznamenán již v roce 2000 a na konci sledovaného období (2005) byl již zcela markantní (2,8 % na ploše F, 21,1 % na ploše C). Všechna provedená statistická hodnocení byla průkazná.

V buk-smrkovém lesním vegetačním stupni byly výsledky hodnocení vlivu hnojení ještě výraznější než ve stupni smrkovém. Všechny provedené statistické testy potvrdily průkaznost vlivu hnojení na olistění stromů. Olistění na počátku pokusu bylo na obou plochách stejné (88 %), v roce 2000 bylo již olistění o něco málo vyšší na hnojené ploše, výrazný pokles olistění byl zaznamenán na kontrolní ploše mezi roky 2001 a 2002 (na hnojené ploše byl tento pokles olistění mnohem menší). Na konci sledovaného období dosáhlo olistění na ploše F 83,3 %, zatímco na kontrolní ploše bylo pouze 71,7 %. Podobně jako ve smrkovém lesním vegetačním stupni se i zde provedené hnojení okamžitě projevilo na snížení symptomů žloutnutí smrkových porostů. Na hnojené variantě bylo pozorováno soustavné snižování žloutnutí (9,1 % v roce 1999, 0,8 % v roce 2005), zatímco na ploše kontrolní byl pozorován opačný trend nárůstu podílu žloutnutí asimilačního aparátu smrku (ze 14,1 % v roce 1999 na 23,3 % v roce 2005). Všechny provedené testy potvrdily statisticky průkazný vliv hnojení na projevy žloutnutí.

V obou sledovaných vegetačních stupních, kde byl zjištěn deficit hořčíku, hnojení pozitivně ovlivnilo olistění stromů a snížilo podíl žlutých jehlic v asimilačním aparátu smrku.

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