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REVIEW

A contribution to the effect of liming on forest soils: review of literature

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ABSTRACT: Extensive forest areas were ameliorated by large-scale liming in the last years in order to prevent proceeding acidification and degradation of forest soils. The hitherto knowledge of liming effects on the function of forest soils still appears insufficient for an unambiguous evaluation. Sorption properties of soils and acidity are favourably affected by liming and the favourable effect is usually manifested in the layer of forest floor humus and in mineral soil within ten years. Reduction of soil acidity stimulates development of a bacterial component of microflora, soil edaphon, and good prerequisites are formed for a release of nutrients from soil organic matter. Improvement of some physical parameters of soils and negative effect of liming on the depth of rooting in spruce, availability of nutrients at some sites and in connection with mechanical soil preparation were also described. A key point of liming effect on forest soils is nitrogen dynamics. Mineralization of nitrogen is stimulated at nitrogen-rich sites with C/N < 30. Nitrogen-limited sites show nitrogen mineralization inhibited by liming with signs of pronounced deficiency in spruce nutrition. A positive effect of liming on nutrition with bases is generally accompanied by an adverse influence on N dynamics in acidic soils under spruce monocultures. Therefore it is possible to state that liming induces relatively marked changes in the soil but the actual growth response of woody species cannot be derived only from these changes.

Keywords: liming and properties of forest soils

In the last few decennia, the atmospheric deposition of nitrogen and sulphur markedly altered chemical and biological properties of forest soils that became "less capable" of providing sufficient nutrition to forest stands. Soil acidification has been an issue of intensive research. Acidification is a natural consequence of life processes in soils and occurs very slowly in natural conditions. Acid depositions from industrial sources lead to accelerated acidification of soil environment connected with higher representation of free H^+ ions, on the other hand it is characterized by a reduced content of bases (Ca, Mg and K) in the form available to plants. The acid inputs can be compensated by soil properties to a certain extent. A failure of buffering capacities is shown in stages within certain pH intervals and is connected with changes in ecological characteristics such as forest floor humus accumulation, delayed biological cycling of nutrients and impaired availability of mineral nutrients.

Buffering capacity of soils is severely limited on acidic soils under spruce monocultures. Acid spruce litterfall, lump shifts in mineralization caused by changed climatic conditions can result in increased concentrations of hydrogen or aluminium ions in soil solution and act as a chemical stressor to the vitality of woody species root system (MÍCHAL 1994). Symptoms related to the effect of aluminium on the root system of forest tree species were described by CRONAN and GOLDSTEIN (1989). Soil acidification can contribute to new ratios between concentrations of individual ions in the soil (SCHULZE et al. 1989) and be one of the factors decreasing the saturation of sorption complex with bases (HOFFMAN et al. 1990), growing aluminium concentration (RASMUSSEN 1986), growing concentrations of iron and manganese (GOBRAN et al. 1993). The character of soil substrate affects the uptake of trace elements such as boron (NILSON, WIKLUND 1995). Contrasting with the unambiguously unfavourable effect of acidification on forest stands ULRICH (1989) presented a literature review assuming both spruce and beech to be species naturally tolerant to soil acidity. Strategy used by forest tree species to "avoid" the toxicity of aluminium in soil was described for example by KREUTZER (1995).

Extensive forest areas were ameliorated by large-scale liming in the past in order to prevent proceeding degradation and to improve chemical and biological characteristics of forest soils. The hitherto knowledge of liming effects on forest soils still appears insufficient for an unambiguous evaluation of its significance. Liming can result in an increased reserve of available bases; their influence on the dynamics of vitally important nitrogen was considered as negative many times and individually depends on the site character.

As the issue of liming effects on forest soils based on the hitherto research results appears still disputable, we attempted to make a review of available literature and to draw conclusions for forest practice so that measures applied to forest soils can lead to the best possible improvement of their nutritive values also in a long-term perspective.

EFFECT OF LIMING ON THE LAYER OF FOREST FLOOR HUMUS

Viewed from a short-time horizon, liming of forest stands results in decreased active and hydrolytic acidity in forest floor humus, an increase being apparent after two years (PODRÁZSKÝ 1993a,b; ERSTAD et al. 1993; FORMÁNEK, KULHAVÝ 2001; NIHLGÅRD et al. 1988; KULHAVÝ 2000; KREUTZER 1995) and even after 8–12 years from the application of limestone (KLIMO et al. 2000; GEARY 1996; SCHULLER 1995). For example MAREŠ (1992) observed an increase in soil acidity by 0.4 (active) and 0.3 (exchangeable) after 2.5 years from liming. No effect on the acidity of forest floor layer was observed after aerial liming without previous soil preparation (PEŘINA 1988) even after more than 10 years from the application of limestone (LHOTSKÝ 1971).

Liming changed the properties of sorption complex (BCC – base cation content, CEC – cation exchange capacity, BS – base saturation). After liming, there were many cases in which BCC increased (NIHLGÅRD et al. 1988; GEARY 1996; BAKKER et al. 1999) even after the aerial application of limestone (PODRÁZSKÝ 1992b), being higher even 8 years later. BS dropped after liming of soil pre-treated by ploughing (PEŘINA 1988), not being altered by liming in some cases at all (PODRÁZSKÝ 1993a). CEC increased after liming (PODRÁZSKÝ 1993a,b; DEROME 1990; CZERNEY, MAI 1970; KREUTZER 1995) remaining raised even after 8 years (JUNCKER 1995). In comparison with the situation before liming the value of CEC did not differ as late as after a 12-year period only (KLIMO et al. 2000). In the case when liming was connected with mechanical soil preparation, the CEC value dropped (PODRÁZSKÝ 1992b). Saturation with bases increased after liming (MAREŠ 1992; PODRÁZSKÝ 1993a,b; KREUTZER 1995; CZERNEY, MAI 1970; ORLOVSKIJ 1982; ANDERSSON, PERSSON 1988; PODRÁZSKÝ 1992b) and the increase was obvious even after aerial application without soil preparation (PEŘINA, PODRÁZSKÝ 1988). CEC was higher even 8 years after the treatment (KREUTZER 1995; JUNCKER 1995), and it was only after 12 years when the effect of liming on base saturation in forest floor humus was not detectable. KLIMO et al. (2000) did not find any change in base saturation after 12 years from the amelioration liming, and similarly like CEC and BCC the base saturation dropped after liming combined with mechanical soil pre-treatment (PODRÁZSKÝ 1992b).

Total nitrogen supply (N_t) in forest floor humus was higher two years after liming (MATZNER 1985; LHOTSKÝ, VINŠOVÁ 1981; PODRÁZSKÝ 1992b), sometimes it was not affected at all (PODRÁZSKÝ 1993b), and in many a case liming reduced N_t in the humus layer (SEIBT, REEMTSMA 1977; LETTL 1992; MAI, FIEDLER 1979). N_{org} (proteins and amino acids) was stabilized in the humus layer after liming by reaction with quinons at the formation of N-rich complexes and protected against microbial decomposition (FLAIG et al. 1975). Induced wash-out of nitrogen from the forest floor humus was described by KREUTZER (1995), who reported that as much as 75% of losses were in the form of organic compounds. Increased N of microbial biomass 7 years after liming was detected by LÜTZOW et al. (1992). Nitrification in humus was mostly stimulated by liming (MAI et al. 1980; OLSEN, BAKKEN 1986; KILLHAM 1990; MOHAMED et al. 1993; DAVIDSON, SCHWANK 1986; NOVÁK 2000; PERSSON 1988, 1994; SCHULLER 1995) – even after 28 years (LETTL 1991). Cases when nitrification decreased due to liming were reported by LETTL (1991) in stands of European mountain ash and birch where nitrification in forest floor humus dropped both immediately after liming and after 28 years, exceptionally also in the upper humus layer under spruce monocultures. There are cases when ammonification and release of NH_4^+ into the environment increased after liming (LHOTSKÝ, VINŠOVÁ 1981) even after 28 years (LETTL 1991); on the other hand, liming sometimes inhibited ammonification for more than three decades (LETTL 1992). There are studies according to which the effect of liming on ammonification was not found 12 years after the last application of dolomitic limestone (FORMÁNEK, KULHAVÝ 2001; FORMÁNEK 2000). As long as the value of C/N ratio in forest floor humus was below 30, the intensity of nitrogen mineralization was stimulated by liming (NOMMIK 1979; PERSSON 1988). In less favourable conditions (C/N > 30) nitrogen mineralization decreased after liming (PERSSON 1988). Liming resulted in a moderate increase of C/N in the forest floor humus layer (PODRÁZSKÝ 1993a) or just in the litterfall layer (FORMÁNEK, KULHAVÝ 2001). Some sources mentioned a decrease in C/N after forest soil liming, the reason being nitrogen accumulation to SOM (PERSSON 1988; MÍCHAL 1994; ANDERSSON 1999) while others did not report any C/N change (MAREŠ 1992; PODRÁZSKÝ 1993b; KLIMO et al. 2000; FORMÁNEK, KULHAVÝ 2001; LOHM et al. 1984). Liming had no influence on nitrogen losses due to denitrification (HELLMAN 1993; PAPKE-ROTHKAMP 1994), but the incorporation of NH_3 into organic matter was described (AXELSSON, BERG 1988; STEVENSON 1982). The forest floor humus supply and C_t were lower after liming (MAREŠ 1992; KLIMO et al. 2000; FORMÁNEK 2000; KREUTZER 1995) even after aerial application, ploughing and excavating (PEŘINA

1988). In general, liming reduces the C_t supply in soils rich in nitrogen (NOHRSTED 2001). ANDERSSON (1999) described the effect of liming on the wash-out of DOC and DOM from the mor form of humus, which was affected by temperature at forest sites or depended on pH whose increase accelerated the intensity of bacterial activity. If forest soils are poor in nitrogen, liming does not stimulate the decomposition of organic matter but rather increases nitrogen deficiency (KULHAVÝ 1992a).

Respiration in forest floor humus was stimulated within a short time after liming (PODRÁZSKÝ 1992a,b; MAI et al. 1980; MATYSOVÁ, 1999; LHOTSKÝ, VINŠOVÁ 1981; MEIWES et al. 1986; MATYSOVÁ 1999; PERSSON 1988; KREUTZER, ZELLES 1986; NÖMMIK et al. 1984; ANDERSSON 1999) and the trend was observed to persist even after 12 or 28 years (FORMÁNEK 2000; LETTL 1991). In some cases, respiration was not affected by liming (MATYSOVÁ 1999; PODRÁZSKÝ 1997) or it decreased in a shorter (PODRÁZSKÝ 1992a; LETTL 1992) or longer period of time that lapsed since limestone application (PERSSON 1988). After half a year, liming had no influence on cellulose decomposition (LHOTSKÝ, VINŠOVÁ 1981; BADALUCCO et al. 1992; UCHMANSKI et al. 1995), soil phosphatase activity (BADALUCCO et al. 1992), and on soil catalases (FORMÁNEK 2000) and enzyme activity in general after a long time (KROMKA et al. 1999). The activity of soil dehydrogenase was stimulated by liming (BADALUCCO et al. 1992).

The number of bacteria in forest floor humus increased 1–2 years after liming (LHOTSKÝ, VINŠOVÁ 1981; LETTL 1992; MAI et al. 1980) and remained increased even after 28 years (LETTL 1991). In other cases the bacterial component was unaffected from the short-time aspect (PERSSON 1988) or from the long-time aspect (LETTL 1991). The number of actinomycetes increased after liming (LHOTSKÝ, VINŠOVÁ 1981; ZELLES et al. 1990), remaining at a lower level even after 28 years or not having been affected by liming at all (LETTL 1991). Their increased occurrence in connection with liming was also described (KOCIÁNOVÁ, STREŠKO 1999; PERSSON 1988). Soil fauna showed a positive effect of liming that resulted in an increased number of earth worms (PERSSON 1994; MAKESCHIN 1991a) and other invertebrates – molluscs, polypods, some groups of unicellular orga-nisms (NOHRSTED 2001). The abundance of mycophages, spider mites, springtails (PERSSON 1988) was not affected by liming while the number of nematodes was reduced. Abundance of some animal species increases after liming while abundance of other species decreases (SCHULER 2002).

Contents of available potassium (LHOTSKÝ, VINŠOVÁ 1981) and available phosphorus (MATZNER 1985; MAREŠ 1992; BAIER, BAIEROVÁ 1985; PODRÁZSKÝ 1992b) were increased after liming. PODRÁZSKÝ (1993b) reported that the contents of available potassium and phosphorus remained sometimes unaffected after liming while according to some sources the supply of these elements decreased (SEIBT, 1977; PODRÁZSKÝ 1993a,c). Available aluminium and magnesium increased in forest floor humus after liming (PODRÁZSKÝ 1992b, 1993b; DEROME 1990; SCHULER 1995) – both in connection with soil pre-treatment (MATZNER 1985) and after a longer time period (KLIMO et al. 2000). Mg deficiency was found after application of limestone in spruce stands (LUNDELL et al. 2001). Peatlands in Finland and Sweden exhibited boron deficiency after liming, due to its absorption into soil organic matter (KREUTZER 1995). The Ca/Al ratio decreased (BAKKER et al. 1999), and lower concentration and mobility of exchangeable aluminium were detected even 8 years after liming (JUNCKER 1995). Toxicity of heavy metals was neutralized by their immobilization with simultaneous formation of organic complexes (SCHULER 1995, 2002).

Liming improved some physical properties of soils – a slight increase in actual moisture, relative moisture and permeability (LHOTSKÝ, VINŠOVÁ 1981) and an increase in the diffusion coefficient of gases due to higher activity of earthworms (SCHACK-KIRCHNER et al. 1998).

EFFECTS OF LIMING ON MINERAL SOIL CHARACTERISTICS

Active and exchangeable acidity in mineral soil was observed to decrease after liming (ABRAHAMSEN 1994; NÖMMIK 1984; NIHLGÅRD et al. 1988; GEARY et al. 1996; SCHULER 1995; BAKKER et al. 1999), usually with some delay and this beneficial effect was shown for decades, the reason being low solubility of lime (MEIWES 1995). Shortly after liming (MAREŠ 1992; LHOTSKÝ 1971; KLIMO, VAVŘÍČEK 1991) and aerial application of limestone without soil pre-treatment (PEŘINA 1988), the mineral soil pH was not affected. LOCHMAN and ŠEBKOVÁ (1998) observed a positive influence of liming on soil to a depth of 40 cm under birch but the mineral soil pH dropped under spruce despite of a positive effect on the layer of forest floor humus. The level of BCC in mineral soil increased after liming (PODRÁZSKÝ 1992b; NIHLGÅRD et al. 1988) as well as after aerial application of limestone without soil pre-treatment (PEŘINA 1988). A decrease was found if the soil was treated with plough (PEŘINA 1988), and sometimes the effect on BCC was not to be observed at all (PODRÁZSKÝ 1993a). The value of CEC increased after liming (PODRÁZSKÝ 1993a,b; DEROME 1990; CZERNEY, MAI 1970; PODRÁZSKÝ 1992b; KREUTZER 1995) and the stability of 3-layer silicates in soil increased (SCHULER 1991). In connection with mechanical soil preparation and disturbance of soil surface, the application of lime resulted in decreased CEC (PODRÁZSKÝ 1992b). Saturation with bases in mineral soil increased after liming (PODRÁZSKÝ 1993a,b; DEROME 1990; CZERNEY, MAI 1970; ANDERSSON, PERSSON 1988; PODRÁZSKÝ 1992b; KREUTZER 1995); in some cases (12 years after liming) the values of CEC and BCC were not affected (KLIMO et al. 2000).

Supply of total nitrogen in mineral soil (B horizon) increased due to the wash-out of DON from forest floor humus and due to changes in its adsorption properties – demonstrated by field research and laboratory tests

(ANDERSSON 1999). Many times there was a decrease in N_t supply after liming from a short-time aspect (SEIBT, REEMTSMA 1977; MAI, FIEDLER 1979) as well as even three decades after the limestone application (LETTL 1991, 1992). After a year (MOHAMED et al. 1993; DAVIDSON, SCHWANK 1986; NOVÁK 2000; PERSSON 1988, 1994; KREUTZER 1995) and also after 28 years from liming (LETTL 1992) the intensity of nitrification in mineral soil increased. In some cases (12 years from liming) nitrification remained unaffected by liming (FORMÁNEK, KULHAVÝ 2001; FORMÁNEK 2000) and decreased within the whole interval of 28 years under stands of European mountain ash and birch (LETTL 1991, 1992). Ammonification in mineral soil was higher within the whole interval of 28 years (LHOTSKÝ, VINŠOVÁ 1981; LETTL 1991), other studies reported its decrease one and even 28 years after liming (KULHAVÝ 1992b; LETTL 1991, 1992). Liming had no influence on nitrogen losses due to denitrification from the mineral layers of soil profile (HELLMAN 1993; PAPKE-ROTHKAMP 1994). A drop of C/N due to nitrogen accumulation into SOM (PERSSON 1988; MÍCHAL 1994) after liming was detected; the results of other studies did not demonstrate any influence on C/N in mineral soil (KLIMO et al. 2000; FORMÁNEK, KULHAVÝ 2001; LOHM et al. 1994). Supply of C_t (B horizon) was higher after liming due to the accumulation of DOM from the forest floor humus (ANDERSSON 1999), accompanied by better humification (PODRÁZSKÝ 1993b; SCHULER 2002). In other cases the quality of humus substances was not affected (LHOTSKÝ, VINŠOVÁ 1981).

Respiration in mineral soil increased with an off-set in several years after liming (NÖMMIK 1984; ANDERSON 1994), in some cases the effect was not demonstrated (FORMÁNEK 2000). Abundance of earthworms was higher even in mineral soil (MAKESCHIN 1991a), the content of available potassium (LHOTSKÝ, VINŠOVÁ 1981; PODRÁZSKÝ 1992b) and phosphorus also increased due to the slowdown of their movement into lower layers of soil horizon by immobilization and development of insoluble phosphates (LHOTSKÝ, VINŠOVÁ 1981). Improved availability of phosphorus to plants was reported by HAVERAAEM (1978), BAIER and BAIEROVÁ (1985) and HINDAR (1994).

Higher content of available calcium and magnesium in mineral soil after amelioration liming (MATZNER 1985; PODRÁZSKÝ 1992b; NIHLGÅRD et al. 1988) was observed also after soil pre-treatment (PODRÁZSKÝ 1993a). The effect of liming on available potassium in a time horizon of 5 years (KLIMO, VAVŘÍČEK 1991), on available phosphorus in a short-time horizon (PODRÁZSKÝ 1993a,b) and also after 5–12 years (KLIMO, VAVŘÍČEK 1991; KLIMO et al. 2000), and on available calcium and magnesium 2.5 years after liming (E horizon) as well as after five years (MAREŠ 1992; KLIMO, VAVŘÍČEK, 1991) was not observed. Adverse impacts of liming on the content of available K (SEIBT, REEMTSMA 1977; PODRÁZSKÝ 1993a,c), available P in E horizon (SEIBT, REEMTSMA 1977; MAREŠ 1992), and available Ca and Mg (PODRÁZSKÝ 1993a,c) even with no soil pre-treatment (PODRÁZSKÝ 1993a) were reported as well.

Liming increased the mobility of Cu, Pb, Fe and Zn (pH > 6) in mineral soil (HINDAR 1994; NIHLGÅRD et al. 1988; LILJELUND, NIHLGÅRD 1988), on the other hand suppressing the mobility of Mn and Cd (NIHLGÅRD et al. 1988). In terms of physical parameters, liming slightly increased actual moisture, relative moisture and permeability (LHOTSKÝ, VINŠOVÁ 1981).

EFFECT OF LIMING ON THE ROOT SYSTEM AND MYCORRHIZAS

As a result of liming, the concentration of nutrients in the rhizosphere increased with the exception of Ca whose amount in the rhizosphere decreased with the exception of mineral soil (B horizon). Liming extended the length of the zone in which roots can induce a pH increase; growth of fine roots (both length and biomass) as well as the uptake of nutrients were stimulated. Specific length of roots was not influenced by liming; the ratio of live/dead roots increased (BAKKER et al. 1999). MURACH and SCHUNEMANN (1985) demonstrated increased growth and re-distribution of fine and medium-size roots in forest floor humus (HAHN 1994). Better rooting density in the mineral layer of soil under beech stands was found after liming by MURACH (1988). KREUTZER (1995) described the effect of liming on the root system in the sense of increased growth of fine and medium roots in the surface humus layer and decreased formation of fine roots in mineral soil. An increase in underground biomass (KREUTZER 1995) as well as a change in the morphology of mycorrhizas in dependence on soil pH (SÖDERSTRÖM 1988) were described. Six years after liming, the number of mycorrhizal roots increased in forest floor humus and in the layer of mineral soil (NOWOTNY et al. 1998). After liming the root biomass exhibited more nitrogen, nitrate-reductase activity of spruce remained unaffected, and the nitrate-reductase activity of roots in *Oxalis acetosa* was stimulated by liming (GEBAUER et al. 1998). After liming, the amount of citrate and malate in mycorrhizal roots increased 1.4 times and 1.3 times, respectively (NOWOTNY et al. 1998); the proportion of dead root biomass (necromass) in a 105-year old spruce stand was also increased (PERSSON H. 1988).

CONCLUSIONS

The reviewed sources of literature indicate a favourable influence of liming on active and exchangeable acidity in the layer of surface humus. With some delay the effect was also manifested in mineral horizons. The more favourable sorption capacity (BCC, CEC, BS), increased contents of available elements (Ca, Mg, P, K) in forest floor humus as well as in mineral soil indicate a beneficial influence of liming on the chemistry of forest soils. The massive development of microflora and bacterial components of edaphon in surface humus and mineral soil create good prerequisites for a release of nutrients from soil organic matter and for their availability to forest stands. Liming was shown to have only a little effect on the physical properties of soils with a consequence of increased actual and relative moistures, permeability and diffusion of gases. The influence of liming on the root system of spruce stands is accompanied by development of roots in forest floor humus and by reduced formation of roots in mineral soil with deeper rooting of beech being also quite apparent.

Negative consequences of liming recorded in the sorption complex of soils were found in connection with mechanical pre-treatment and disturbance of soil surface. There are sporadic reports about a lower supply of available nutrients (Ca, Mg, K, P) in mineral soil. Mobility of heavy metals (Cu, Pb, Fe and Zn) was higher in the soil only at pH > 6.

Most disputable is the effect of liming on nitrogen dynamics. Liming was observed to stimulate nitrogen mineralization at sites rich in nitrogen with C/N < 30, which is connected with a risk of excessive contamination of groundwaters with nitrates. In soils with nitrogen being a limiting nutrient, net mineralization was inhibited by liming and by accumulation into SOM and nitrogen deficiency even increased. The effect of liming on nitrogen dynamics was favourable under stands of European mountain ash and birch, being accompanied by decreased nitrification and increased intensity of ammonification.

It follows from a conclusive evaluation that the beneficial effect of liming on nutrition with bases is accompanied by a generally negative impact on the dynamics of nitrogen in acidic soils under spruce monocultures. Liming of stands at nutrient-poor and acidic sites is accompanied by impaired nutrition with nitrogen; on the other hand, intensive nitrification in nitrogen-saturated soils would lead to the contamination of groundwaters.

Therefore a conclusion can be drawn that liming induces relatively pronounced soil changes but the actual growth response of forest tree species cannot be derived only from these changes.

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Příspěvek ke vlivu vápnění na lesní půdy: literární přehled

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ABSTRAKT: Za účelem zabránit postupující acidifikaci a degradaci lesních půd byly v minulých letech rozsáhlé lesní soubory meliorovány velkoplošným vápněním. Souhrn dosavadních poznatků o jeho vlivu na funkci lesních půd je stále nedostačující pro posouzení. Sorpční vlastnosti půd a acidita jsou po vápnění příznivě ovlivňovány ve vrstvě nadložního humusu i v minerální půdě a v mnoha případech se projevují do deseti let. Snížením půdní acidity je stimulován rozvoj bakteriální složky mikroflóry, půdního edafonu a vytvářejí se dobré předpoklady pro uvolňování živin z půdní organické hmoty. Zlepšení některých fyzikálních parametrů půd a negativní vliv vápnění na hloubku prokořenění u smrku, přístupnost živin na některých stanovištích a ve spojení s mechanizovanou přípravou půdy byly také popsány. Klíčovým bodem vlivu vápnění na lesní půdy je dynamika dusíku. Mineralizace dusíku je stimulována na stanovištích bohatých na dusík s C/N < 30. Na stanovištích N-limitovaných je mineralizace dusíku vápněním inhibována se známkou výrazného deficitu ve výživě smrku. Pozitivní vliv vápnění na výživu bázemi je provázen obecně negativním vlivem na dynamiku dusíku v kyselých půdách pod smrkovými monokulturami. Je tedy možné konstatovat, že vápnění vyvolává poměrně výrazné půdní změny, ale z nich samotných nelze ještě usuzovat na skutečnou růstovou odezvu samotných dřevin.

Klíčová slova: vápnění a vlastnosti lesních půd

Pro zastavení zvyšující se acidifikace a degradace lesních půd byly v minulých desetiletích rozsáhlé lesní soubory meliorovány velkoplošným vápněním. Údaje o vlivu vápnění pro posouzení jeho významu v lesní produkci jsou stále nedostačující. Nejen intenzivní výzkum, ale i dosavadní literární prameny a jejich souhrn ukazují jednu z možných cest k formulaci závěrů pro praxi a dlouhodobé zvyšování nutričních vlastností na stanovištích. Ve studii jsou sumarizovány vlivy vápnění na vlastnosti v nadložním humusu i v minerální půdě. Vápněním byla snižována aktivní i výměnná půdní acidita. Sorpční vlastnosti půd, charakterizované S, T, V, byly většinou příznivější v nadložním humusu i v minerální půdě a negativně byly pozměněny po vápnění v kombinaci s narušením půdního povrchu. Zásoba celkového dusíku v nadložním humusu často klesala a zvyšovala se v minerální půdě v důsledku vyplavování dusíkatých organických látek. Kinetika mineralizace dusíku byla provázena aktivací nitrifikace a amonizace. Zásoba celkového uhlíku klesala v nadložním humusu a vzrůstala v minerální půdě v důsledku vyplavování rozpustných organických látek. Podle velkého počtu studií byla respirace v nadložním humusu vápněním stimulována a v minerální půdě nebyl tento projev výrazný. Rozklad celulózy, aktivita půdní katalázy a fosfatázy v nadložním humusu nebyly ovlivněny, stimulována byla půdní dehydrogenáza. Po vápnění byla zjištěna vyšší početnost bakterií, aktinomycet a půdní fauny. Obsah přístupných živin (Ca, Mg, K, P) byl vyšší, nicméně některé práce ukázaly opačné tendence spojené s poklesem přístupného K a P nebo deficiencí B, popř. Mg a Ca. Fyzikální vlastnosti půdy byly po vápnění nepatrně příznivější a mobilita těžkých kovů byla neutralizována. V důsledku vápnění se zvýšila koncentrace živin v rizosféře, velikost zóny inducibilního zvyšování pH, růst jemných kořínků v nadložním humusu a množství dusíku v kořenové biomase. Za negativní se považuje snížená formace jemného prokořenění smrku v minerální půdě. Kvalitnější prokořenění v minerální vrstvě půdy bylo patrné pouze pod bukovými porosty. Vápnění nemělo vliv na nitrátreduktázovou aktivitu kořenů smrku, vyšší byla koncentrace citrátu a malátu v kořenové biomase.

Literární souhrn ukazuje vliv vápnění na půdní aciditu, sorpční a biologické vlastnosti jako pozitivní; nejvíce diskutabilní zůstává otázka dynamiky dusíku. Mineralizace dusíku je stimulována na stanovištích dusíkem saturovaných a může být provázena rizikem nadměrné kontaminace podzemních vod. V půdách dusíkem limitovaných je čistá mineralizace po vápnění nižší a deficience dusíku je vyšší. Ze závěrečného hodnocení vyplývá, že pozitivní vliv vápnění na výživu bázemi je provázen obecně negativním vlivem na dynamiku dusíku v kyselých půdách pod smrkovými monokulturami. Je tedy možné konstatovat, že vápnění vyvolává poměrně výrazné půdní změny, ale z nich samotných nelze ještě usuzovat na skutečnou růstovou odezvu vlastních lesních dřevin.

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