http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 11 (9): 1258-1262, 2008
ISSN 1028-8880

Impact of Tree Species on Nutrient Stocks in the Forest Floors of a Temperate Forest Ecosystem

[1]Ali Bagherzadeh, [2]Rainer Brumme and [2]Friedrich Beese
[1]Department of Agriculture, Faculty of Agriculture, Azad University of Mashhad, Emamyeh Boulevard, P.O. Box 91735-413, Mashhad, Iran
[2]Institute of Soil Science and Forest Nutrition, Georg-August-University of Geottingen, Buesgenweg 2,37077 Goettingen, Germany

Abstract: To investigate the effect of silvicultural methods on forest floor C, N and elements stocks an experiment was carried out by sampling the forest floors of a 100-120 years old species including beech, Norway spruce and mixed beech-spruce at the Solling forest, Germany. While the stocks of carbon and nitrogen in the forest floors of pure beech and spruce were significantly influenced by species specific differences of litter quality ($p<0.001$), no significant differences were detected between pure and mixed species stands. Forest floor mass, some elements concentrations and C/nutrient ratios were significantly affected by tree species differences, while no clear dependency between pH and site specific effects was found among pure stands. Acid element concentrations in the forest floors of pure spruce were remarkably higher than the values obtained at beech stand, while the stocks were to some extent modified in mixed silviculture. The base-pump effect of beech significantly controlled variation between mono cultures on calcium stocks, while the acidifying effect of spruce in mixtures resulted in modification of Ca stocks of forest floors. The status of other nutrient elements at mixed species cultures due to variation in nutritional properties and composition of litter compared to pure species were between the range of values observed in mono cultures.

Key words: Beech, spruce, forest floor, nutrient, litter

INTRODUCTION

Forest floor is an important link in the biogeochemical cycle of nutrients in forest ecosystems and essential for the nutritional status of forest stands. Observations have shown differences in accumulation and properties of the forest floor under various species (Rothe *et al*., 2002). The differences have been attributed to various factors such as environmental factors, e.g., climate (Berg *et al*., 2000), nutrient content of the litter (Berg, 2000; Berg and Meentemeyer, 2002), the C/N and lignin/N ratios (Berger *et al*., 2002). The mechanisms by which tree species influence forest floor acidity, base cations and heavy metal elements are several fold and include interspecific differences in the uptake of cations and anions (Vesterdal and Raulund-Rasmussen, 1998), nitrogen mineralization and immobilization (Corre *et al*., 2003) and the stimulation of mineral weathering (Tice *et al*., 1996). Soil properties can affect forest floor decomposition rates through influencing (i) initial litter quality, notably the concentration of nutrients (Norden, 1994; Augusto *et al*., 2000) and recalcitrant organic compounds like lignin and tannins (Sanger *et al*., 1996) and (ii) the microenvironment in which litter decomposition takes place, including the communities of soil fauna and microorganisms. Tree species differ in their effect on soil development and nutrient cycling by their short-term (decades) influence on the biological activity and the nutrient availability of soil in the forest ecosystems (Finzi *et al*., 1998; Vesterdal, 1999). Differences between species in their effect on soil properties are most often explained by differences in the quantity and quality of the aboveground litter production. Norway spruce and European beech are the most widespread conifer and deciduous tree species in central Europe. Important differences between these species occur in their effects on soil and soil solution properties. Differences in rooting patterns lead to different soil exploitation among species reflect the annual rate of base cations incorporation into the above ground foliar litter. The base-pump effect of beech trees by enlarging the soil volume exploited by the roots is a basic means by which forest stands incorporate soil mineral nutrients in the living biomass by employment of nutrients from the mineral soil. Norway spruce is commonly described as a

Corresponding Author: Ali Bagherzadeh, Department of Agriculture, Azad University of Mashhad, Emamyeh Boulevard, P.O. Box 91735-413, Mashhad, Iran Tel: +98-511-8642166

tree with a flat root system and restricted root development with much lower penetration energy than most deciduous trees (Rothe and Binkley, 2001). In mixed species silviculture root distribution system is altered compared to monocultures. Spruce roots more shallowly and beech roots more deeply resulted in greater possibilities for nutrient acquisition. In addition, the deep-rooted beech in mixed stands may also be able to access nutrients below the rooting zone of spruce, affecting the nutrient storage and turnover of the whole soil profile. The objective of the present study was to investigate impacts of different silvicultural methods on nutrient stocks and other chemical properties of the forest floors under similar environmental conditions on a single soil type. The study focused on the following aspects of forest floor chemistry: (i) pH and C/nutrient ratios and (ii) element stocks, with respect to the effect of different tree species in pure and mixed cultures on forest floors.

MATERIALS AND METHODS

Study site: Study site is located at the Solling forest about 70 to 80 km southward Hannover, Lower Saxony, Germany (51°47′N and 9°37′E) on slightly inclined (2-4°) slopes. The area is situated at 500 m elevation a.s.l. with a mean annual air temperature of 6.4°C and an annual precipitation of 1068 mm (Tiktak *et al*., 1995). The dominant soil type is podsolic, slightly pseudogleyic Dystric Cambisol (FAO) developed on triassic sandstone covered by a layer of loess with a thickness varying from 0.2 to 2 m (average 80 cm). Morphological humus forms are typical moder and soil texture is dominated by silty loam. Three adjacent stands were chosen for the study: a mature (100-120 years old) Norway spruce (*Picea abies* L. karst.) stand partly covered by grass, a 100-120-year-old beech (*Fagus sylvatica* L.) stand and a mixed spruce-beech stand covered by 100 to 120 years old trees.

Soil sampling and chemical analyses: Undisturbed forest floor samples were taken randomly from each stand (n = 100) by using a stainless steal auger and were stored at 4°C for a few days before processing. Forest floor samples were sieved through an 8 mm mesh to remove roots, dried at 105°C and then weighed. The total C and N concentrations of the forest floors were analysed by dry combustion with a CN-auto analyser (Vario, Elementar Analysensysteme, Hanau, Germany). The elements Phosphorous (P), Sulphur (S), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Manganese (Mn), Iron (Fe) and Aluminium (Al) in the humus samples were analysed by ICP-AES (Spectro Analytical Instruments, Kleve, Germany) after pressure digestion in 65% concentrated HNO_3. Soil pH was measured with a digital pH meter (WTW GmbH Wesl-Germany) in water and 1 mol L^{-1} KCl.

Statistics analysis: Analysis of variance (ANOVA) were tested by Mann-Whitney U-test at $p<0.01$ and $p<0.001$ levels, performed by the program Statistica version 6.0.

RESULTS AND DISCUSSION

Forest floor mass varied significantly among pure species stands, while the differences between mono and mixed species cultures were negligible ($p<0.001$). The differences on forest floor accumulation among pure species stands can be traced back to reduction in decomposition processes due to excessive atmospheric deposition of nitrogen at spruce compared to beech (42 vs. 21 kg N ha^{-1} a^{-1}) (Meiwes *et al*., 2002). All forest floors were acidic with $pH_{(KCl)}$ ranged from 3.08 at beech stand to 2.97-2.91 at mixed species and spruce stand indicated that pH was not affected by tree specific differences of litter quality (Table 1). The fact that acidifying effects of pure spruce is hardly visible at low pH may be the consequence of general low base content of mineral soil at the experimental area, which does not allow sequestration of large amounts of acid cations in the forest floor markedly lowering pH. The stocks of carbon at beech forest floor was significantly lower than the values observed at pure spruce stand (277.7 vs. 298.0 g kg^{-1}), while the differences between

Table 1: Mean forest floor characteristics of each stand including the pH, total concentrations of carbon and nitrogen, (Standard deviation represent in parentheses)

Stand	$Depth^{ns}$ (cm)	Mass** (mg ha^{-1})	$Moisture^{ns}$ (%)	pH^{ns} (KCl)	(H$_2$O)	C_{org}** (g kg^{-1})	N_t** (g kg^{-1})
Beech	5.03^a	49.0^a	59.5^a	3.08^a	3.81^a	277.7^a	14.2^b
	(0.2)	(10.7)	(2.42)	(0.14)	(0.18)	(35.7)	(1.64)
Mixed	5.41^a	53.2^{ab}	59.4^a	2.97^a	3.66^a	289.9^{ab}	13.6^{ab}
	(0.3)	(18.4)	(9.41)	(0.16)	(0.12)	(34.0)	(1.66)
Spruce	5.77^a	57.5^b	61.0^a	2.91^a	3.62^a	298.0^b	13.0^a
	(0.3)	(21.4)	(8.74)	(0.12)	(0.19)	(30.5)	(1.56)

Values with different superscript letter(s) are significantly different from one another. Significance levels are: ns = not significant, *$p<0.01$ and **$p<0.001$

pure and mixed species (289.9 g kg^{-1}) were negligible (Table 1). Nitrogen concentration in the forest floor of beech was significantly greater than the values found at spruce stand (14.2 vs.13.0 g kg^{-1}), while no significant differences were detected among mono and mixed species (13.6 g kg^{-1}) cultures. The C/N ratio of the forest floor at spruce stand was significantly higher than at beech (23.0 vs. 19.6), but the ratios not differed significantly among pure and mixed species (21.3). Variation in the size of C and N stocks among pure species appears to be regulated by a combination of interspecific differences in litter production and the rate of litter decomposition (Prescott *et al*., 1993; Stump and Binkley, 1993). According to Meiwes *et al*. (2002) beech in mono culture has leaf litter more rich in N (13.3±1.8 mg g^{-1}) than spruce (11.3±0.9 mg g^{-1}) with similar rate of leaf litter production compared to spruce (2.89 vs. 2.97 t ha^{-1} a^{-1}). Hence, litter of spruce with higher forest floor C/N ratio decomposes more slowly than litter of beech with lower C/N ratio, resulted in higher accumulation of forest floor and more sequestration of carbon at spruce compared to beech stand. It can be deduced from present results that deciduous beech species with lower N use efficiencies and higher N uptake requirement are more resistant to atmospheric N additions reflected in significantly narrower C/N ratios than coniferous spruce cultures with high N use efficiencies. In consistent with our results, Berg and Meentemeyer (2002) and Meiwes *et al*. (2002) indicated that increased atmospheric N input retards the later stages of litter decomposition causing a build-up of humus in the system and resulted in alteration of chemical composition of the forest floor which at spruce stand lead to a limitation of calcium stocks due to differences in litter quality. The base-pump effect of beech significantly influenced the concentration of calcium at pure beech stand, while in pure spruce general low base content of litter did not allow sequestration of large amounts of base cation Ca in the forest floor (5.53 vs. 2.99 g kg^{-1}). Statistically no significant differences were observed on the stocks of calcium between mono and mixed species (4.28 g kg^{-1}) cultures, demonstrated that base-pump effect of beech in mixtures has been modified by acidifying effect of spruce (Fig. 1). The Phosphorous concentration at beech stand was in tendency higher than the values observed at pure spruce and mixed species stands (0.96 vs. 0.81-0.86 g kg^{-1}), resulted in narrower C/P ratios at beech as a consequence of higher microbial demand for phosphorous to decompose beech litter. The ratios of C/P mineralization among the three species stands were 14.8-16 times greater than C/N mineralization ratios, typically by an order of magnitude. Tree species strongly affected the stocks of acid

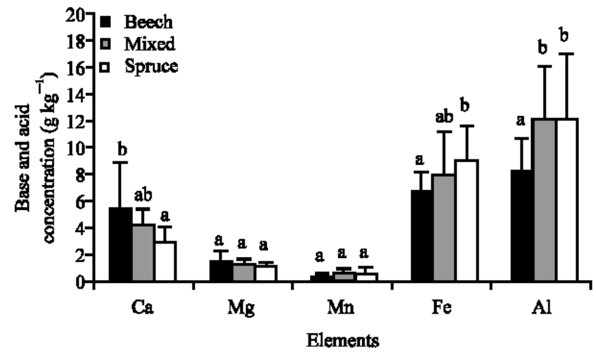

Fig. 1: Mean base and acid concentrations of the forest floors of beech, spruce and mixed species stands, Error bars are 1SD [different alphabet: significant, $p<0.001$]

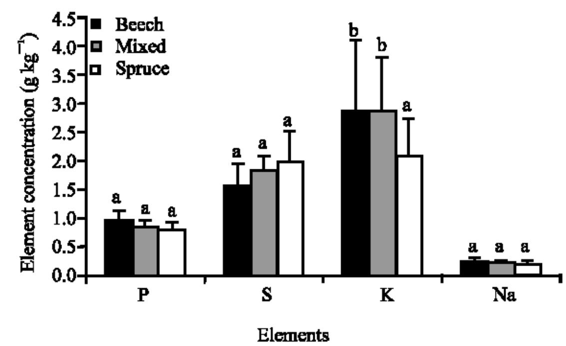

Fig. 2: Mean element concentrations of the forest floors of beech, spruce and mixed species stands, Error bars are 1SD [different alphabet: significant, $p<0.001$]

elements Fe and Al in forest floors. In comparison to beech the acidifying effect of spruce decomposing litter significantly influenced sequestration of acid cations Aluminium (8.23 vs. 12.2 g kg^{-1}) and iron (6.78 vs. 9.04 g kg^{-1}) in the forest floors, however the base-pump effect of beech in mixtures to some extent modified the acid nutrient release in the forest floor. The relatively low concentration values of sulfur (1.58 to 1.98 g kg^{-1}), magnesium (1.52 to 1.16 g kg^{-1}), manganese (0.41 to 0.65 g kg^{-1}) and sodium (0.24 to 0.20 g kg^{-1}) from beech over mixed species to spruce stands were less affected by species specific differences of litter quality, indicating that these elements were not a limiting factor in decomposition rate of litter (Fig. 2). Among pure and mixed species stands spruce had significantly highest forest floor C/K, C/Na, C/Ca and C/Mg ratios, while beech was detected to have the lowest values (Table 2). The ratios of carbon to sulfur and acid elements at beech forest floor were significantly higher than the

Table 2: Mean values for C/nutrients ratios in the forest floors of beech, mixtures and spruce stands

	C/nutrient ratio									
Stand	C/N**	C/P*	C/S*	C/K*	C/Na*	C/Ca*	C/Mg*	C/Mn*	C/Fe*	C/Al*
Beech	19.6^{a}	289.3^{a}	175.7^{b}	96.7^{a}	1157.1^{a}	50.2^{a}	182.7^{a}	895.8^{b}	40.9^{b}	33.7^{b}
Mixed	21.3^{ab}	337.1^{b}	157.5^{a}	101.0^{a}	1260.4^{b}	67.7^{b}	214.7^{b}	475.2^{a}	36.4^{a}	23.9^{a}
Spruce	23.0^{b}	367.9^{c}	150.5^{a}	143.3^{b}	1490.0^{c}	99.7^{c}	256.9^{c}	458.5^{a}	33.0^{a}	24.4^{a}

Values with different superscript letter(s) are significantly different from one another. Significance levels are: ns = not significant, $^{*}p<0.01$ and $^{**}p<0.001$

corresponding ratios at spruce and mixed silvicultures. The processes involved in creating variation in the ratios of carbon to acid and base cations among different forest floors are likely concerned to (1) species specific differences in the production of organic acids from decomposing litter that change the relative quantities of exchangeable base (Ca) and acid cations (Fe, Al) in forest floors, (2) differences in cation uptake and allocation to biomass pools with differing turnover rates. In consistent with Son and Gower (1992) the variation in forest floor C/nutrient ratios among the three adjacent stands indicated that these forest floor variables for the most part might be more influenced by tree specific differences of litter quality than the mineral soil nutrient status as general climatic and edaphic conditions at experimental area were similar.

CONCLUSION

The forest floors exhibited variations in mass, nutrient stocks and C/nutrient ratios between the pure species stands. It was demonstrated that trees may have implications through different root system patterns on species specific composition of litter quality and chemical characteristics of the forest floors. The size of nutrient stocks in mixtures found in our study were within the range measured for the pure stands, revealed that beech may have improved nitrogen stocks and modified acidifying effects of spruce in mixed silviculture. It was demonstrated that mixed silviculture by enlarging the soil volume exploited due to more root distribution pattern compared to spruce with a flat root system and restricted root development indicated more nutrient acquisition in the forest floor. The ability to understand and predict the impacts of mixed-species silviculture will require a substantial set of studies (including species with nutrient-rich litter fall and species with high nutrient-use efficiencies) that examine the frequency and magnitude of the changes in ecosystem pools and fluxes.

ACKNOWLEDGMENTS

We thank D. Gaschick for cooperating in the field and the staff of the central Laboratory of the Institute of Soil Science and Forest Nutrition of Goettingen University for their assistance in chemical analysis. The research study was financially supported by Institut fuer Bodenkunde und waldernaehrung, Georg-August-Universitaet, Goettingen, Germany.

REFERENCES

Augusto, L., J. Ranger, Q. Ponette and M. Rapp, 2000. Relationships between forest tree species, stand production and stand nutrient amount. Ann. For. Sci., 57: 313-324.

Berg, B., 2000. Litter decomposition and organic matter turnover in Northern forest soils. For. Ecol. Manage., 133: 13-22.

Berg, B. and V. Meentemeyer, 2002. Litter quality in a North European transect versus carbon storage potential. Plant Soil, 242: 83-92.

Berg, B., M.B. Johansson and V. Meentemeyer, 2000. Litter decomposition in a transect of Norway spruce forests: Substrate quality and climate control. Can. J. For. Res., 30: 1136-1147.

Berger, T.W., C. Neubauer and G. Glatzel, 2002. Factors controlling soil carbon and nitrogen stores in pure stands of Norway spruce (*Picea abies*) and mixed species stands in Austria. For. Ecol. Manage., 159: 3-14.

Corre, M., F. Beese and R. Brumme, 2003. Soil nitrogen cycle in high nitrogen deposition forest: Changes under nitrogen saturation and liming. Ecol. Appl., 13 (2): 287-298.

Finzi, A.C., C.D. Canham and N. Van Breemen, 1998. Canopy tree-soil interactions within temperate forests: Species effects on pH and cations. Ecol. Appl., 8 (2): 447-454.

Meiwes, K.J., H. Meesenburg, H. Bartens, P. Rademacher and P.P.K. Khanna, 2002. Accumulation of humus in the litter layer of forest stands at Solling: Possible causes and significance for the nutrient cycling. For. Holz., 57: 428-433.

Norden, U., 1994. Leaf litterfall concentrations and fluxes of elements in deciduous tree species. Scan. J. For. Res., 9: 9-16.

Prescott, C.E., B.R. Taylor, W.F.J. Parsons, D.M. Durall and D. Parkinson, 1993. Nutrient release from decomposing litter in Rocky mountain coniferous forests: Influence of nutrient availability. Can. J. For. Res., 23: 1576-1586.

Rothe, A. and D. Binkley, 2001. Nutritional interactions in mixed species forests: A synthesis. Can. J. For. Res., 31: 1855-1870.

Rothe, A., K. Kreutzer and H. Kuechenhoff, 2002. Influence of tree species composition on soil and soil solution properties in two mixed spruce-beech stands with contrasting history in Southern Germany. Plant Soil, 240: 47-56.

Sanger, L.J., P. Cox, P. Splatt, M.J. Whelan and J.M. Andeson, 1996. Variability in the quality of *Pinus sylvestris* needles and litter from sites with different soil characteristics: Lignin and phenylpropanoid signature. Soil Biol. Biochem., 28: 829-835.

Son, Y. and S.T. Gower, 1992. Nitrogen and phosphorous distribution for five plantation species in Southwestern Wisconsin. For. Ecol. Manage., 53: 175-193.

Stump, L.M. and D. Binkley, 1993. Relationships between litter quality and nitrogen availability in Rocky Mountain forests. Can. J. For. Res., 23: 492-502.

Tice, K.R., R.C. Graham and H.B. Wood, 1996. Transformations of 2:1 phyllosilicates in 41-year-old soils under oak and pine. Deoderama, 70: 49-62.

Tiktak, A., M. Bredemeier and Kees van Heerden, 1995. The Solling dataset: Site charactristics, monitoring data and deposition scenarios. Ecol. Modell., 83: 17-34.

Vesterdal, L. and K. Raulund-Rasmussen, 1998. Forest floor chemistry under seven tree species along a soil fertility gradient. Can. J. For. Res., 28: 1636-1647.

Vesterdal, L., 1999. Influence of soil type on mass loss and nutrient release from decomposing foliage litter of beech and Norway spruce. Can. J. For. Res., 29: 95-105.