

Is soil chemistry an indicator of tree nutrition and stand productivity?

Dedicated to Univ. Prof. Dipl.-Ing. Dr. Dr. h.c. Winfried E. H. Blum on the occasion of his 60th birthday

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Sind bodenchemische Kennwerte Indikatoren für die Ernährung und die Produktivität von Wäldern?

Univ. Prof. Dipl.-Ing. Dr. Dr. h.c. Winfried E. H. Blum zu seinem 60. Geburtstag gewidmet

1. Introduction

The nutrient content of the soil imposes a limit on the nutrient availability for plants. Agricultural experiments have demonstrated a close linkage between plant nutrition and the nutrient content in the soil. This experience needs not necessarily apply in forestry. There are several reasons why the linkage between soil chemistry, nutrient content in needles and the Yield Class is weak. A typical property of trees is their longevity. During the lifespan of more than a century both the nutrient demand of the stand and the supply from the soil vary. The nutrient demand is high especially during the first 20 years, when individual trees fiercely compete for growing space. In the early stage of stand development the needle mass

increases every year in order to gain a competitive advantage over neighboring trees. Later on the total amount of foliage remains almost stable during several decades, and only the mass of stem wood increases. Wood consists mainly of carbon, oxygen, and hydrogen, elements that are gained upon photosynthesis. Mineral nutrients from the soil are used as essential components in physiological reactions and only small quantities are tied up in the wood.

Another peculiarity of trees are large nutrient storage compartments for use in times of urgent demand. Such a critical time-span is spring, when large amounts of nutrients are required in order to establish the current foliage within a short time. At nutrient poor sites it may not be possible to exploit the soil within this short time-span to

Zusammenfassung

Wir untersuchten die Beziehung zwischen dem Nährstoffgehalt von Waldböden und den Nadeln um herauszufinden, ob die Baumernährung, repräsentiert durch die Nadel-Spiegelwerte, mit bodenchemischen Kennwerten vorhersagbar ist. Außerdem prüften wir, ob die Ertragsklasse eines Waldbestandes mit zwei häufig verwendeten Maßzahlen, dem C:N-Verhältnis und der Basensättigung, zusammenhängt. Die Ertragsklasse diente dabei als genereller Indikator für die Wachstumsbedingungen. Wir verwendeten einen Teil des größten homogenen Datensatzes für österreichische Wälder (Waldschadensbeobachtungssystem, WBS). Unsere Analyse beschränkte sich auf Fichtenbestände auf Nicht-Karbonatstandorten. Im allgemeinen war die Beziehung zwischen der Baumernährung, der Ertragsklasse und den bodenchemischen Kennwerten schwach. Offensichtlich sind Fichten in der Lage, aus Böden mit stark unterschiedlichen chemischen Eigenschaften die erforderlichen Nährstoffe zu extrahieren. Auch auf sehr nährstoffarmen Standorten können ausreichend Nährstoffe angereichert und in einem dichten biogeochemischen Kreislauf gehalten werden. Mit chemischen Bodenkennwerten läßt sich die Ertragsklasse eines Bestandes nicht vorhersagen. Andere Standortfaktoren, wie etwa das Klima und der Wasserhaushalt, haben offensichtlich einen grösseren Einfluß auf die Baumernährung und das Bestandeswachstum.

Schlagworte: Baumernährung, Chemie des Waldbodens, Nährstoffgehalt von Nadeln, Ertragsklasse, Fichte, Österreichisches Waldschadensbeobachtungssystem (WBS).

Summary

We investigated if the foliar nutrient levels of trees, a proxy for tree nutrition, are closely related to the nutrient content of forest soils. In addition we investigated if the Yield Class, a proxy for the general growing conditions of a stand, is related to two common soil chemical indicators, the C:N ratio and the base saturation. We used a subset of the data from the Austrian Forest Monitoring System (WBS). Our analysis was restricted to sites on non-calcareous parent rock, where stands are dominated by Norway spruce (*Picea abies*). Overall, the relation between tree nutrition, Yield Class, and soil chemical data was weak. Obviously spruce is able to extract the required sufficient amounts of nutrients at a wide range of soil chemical conditions. Spruce efficiently scavenges nutrients over a wide range of soil chemical conditions. Even on poor sites high foliar nutrient levels can be maintained, because nutrients taken up are kept in a tight biogeochemical cycle. We conclude that soil chemical conditions are weak predictors of the Yield Class. Other factors, such as climate and water relations, seem to exert a larger influence on the nutrition and growth rate of spruce forests.

Keywords: tree nutrition, forest soil chemistry, nutrient content of needles, Yield Class, Norway spruce, Austrian Forest Monitoring System (WBS).

the required extent, either for lack of water transport or for lack of nutrient availability. In spring the plant-internal nutrient pool is utilized and sometimes exhausted and is to be refilled during the growing season. Another critical period is the time of root growth, which precedes in many tree species the development of the foliage. Without the supply of nutrients dissolved in the transpiration stream plants rely on internal translocation processes. At sites where plant-internal nutrient transfer processes are involved to a great extent, a loose relationship between the nutrient content in the soil and the amount of nutrients in the plant is expected. The nutrient pool in the soil is the available stock, that maybe used by plants, but alternative processes to fulfill the nutrient demand are also existing. With this background information it seems dubious if a close relation between nutrient content of forest soils and the foliage exists.

A large body of literature suggests, that tree growth can be moderated by means of nutrient addition. The response of the stand to fertilization is interpreted in retrospect by the comparison of different treatments, but a scientifically solid forecast of the effect of individual nutrients is rarely possible. We find a large variability in tree heights and standing biomass on the one hand and nutrient supplies in the respective soils on the other hand and we assume that nutrient rich sites offer more favorable conditions to trees. A frequently offered explanation for the poor predictability is the complexity of forest ecosystems. The term 'complex' substitutes for insufficient understanding of the interactions of nutrients with other growth determining factors. Although the loose relationship between soil chemistry and tree nutrition is seen in published data, it is often attempted to evaluate

the nutritional situation and the growth-rate of a forest stand by means of its soil chemistry.

We evaluate the relation between soil and foliage for selected nutrients. (1) **Nitrogen** is chosen because it is the single most limiting nutrient in forests. Nitrogen is not contained in the parent rock material, but is made available by microbial processes. Plants have developed numerous strategies to take up nitrogen selectively. Nitrogen is enriched in the plant, thereby creating a concentration gradient between the soil and the tree. (2) **Calcium** is chosen because it is used for soil quality parameters. It is derived from many minerals and comprises the major part of the base saturation, a value that represents the protonation status of the exchange complex of the mineral soil. Trees are apparently rarely suffering from Ca deficiency and Ca uptake is unspecific. Surplus Ca is not even re-translocated within the plant, but is locked up in insoluble complexes. (3) **Potassium** is an element in high demand for physiological processes. It is contained in many primary and secondary minerals. At lower pH-values it is very mobile. Its active form within the plants is the free ion, that is readily leached from the foliage. Thereafter it reaches the soil and can be re-absorbed by roots.

As a second indicator of tree-nutrition we investigated the Yield Class as dependent on two integrated indicators of soil chemistry, the C:N ratio and the base saturation. The underlying assumption is that the growth rate of stands depends on the availability of the nutrients from the soil. There are certainly other factors, such as water supply or length of the growing season, that are driving the growth rate, but overall, we expected to identify a pattern, that would corroborate the assumed relation between Yield Class and soil nutrients.

2. Methods

We used the data of the Austrian Forest Monitoring System (WBS). This survey covers the entire country. We restricted our evaluation on sites with non-calcareous parent rock material. On calcareous sites the content of exchangeable Ca is always high and the base saturation is always 100% because the soil is in a chemical equilibrium with free carbonates. Therefore no pattern of the relation between base saturation and the nutrient content in the foliage can be expected. Besides, the water holding capacity of these sites is often low, because soils are mostly shallow and the content of coarse material is high. When water is the growth limiting factor, the mineralization of soil organic matter is slow and consequently the nitrogen supply is slow. Moreover we excluded sites which are dominated by deciduous trees, because the nutrient content in leaves is generally much higher than in needles. We expected that our selection of spruce-dominated stands at non-calcareous sites is a consistent data set.

The sampling locations of the WBS are on a grid with a mesh of 8,7 km. Soil samples were collected from 3 soil pits in the close vicinity of the respective grid point. They were collected from the forest floor and several layers from the mineral soil (0–10, 10–20, 20–30, 30–50, 50–80 cm). The samples from the 3 individual pits were pooled in order to obtain one representative sample per horizon and site. The field methods are described in detail in ENGLISCH et al. (1992).

Chemical soil analysis included the pH-value (0.01 M CaCl_2), total contents of C, N, contents of exchangeable cations (0.1 M BaCl_2 -extract), and acid extractable cations ($\text{HNO}_3/\text{HClO}_4$ digest). The laboratory methods are described in BLUM et al (1996) and in ENGLISCH et al. (1992). The chemical properties of individual soil horizons were combined to a weighed mean value in order to obtain an integrated soil chemical parameter for the entire soil profile instead of independent analyses of individual horizons. The weight factor was chosen, that the uppermost soil horizons have the larger and the lower soil horizons smaller weight, according to the availability of nutrients at the shallow root distribution in Norway spruce forests. Weight factors were 1, 0.8, 0.5, 0.2 for the layers 0–10, 10–20, 20–30, 30–50 cm, respectively.

Needle samples were collected from 3 predominant trees close to the grid point. The needles of the last year's shoots were used. Chemical analysis included the total content of N, K, Ca, and of other elements that are not used in this

study. Field and laboratory methods are described in FÜRST (1992). Needle samples are annually collected at the experimental sites. In our investigation we used the results from the year 1989.

As a measure for the forest growth rate we used the Yield Class, according to the locally valid Yield Table (MAR-SCHALL, 1975). The Yield Class is the average annual stem increment rate of a stand within 100 years. Its advantage over the actual growth rate is its independence of stand age. For the data evaluation we used the statistical packages SAS (1992). We calculated linear regressions with the soil nutrient content as the independent and the nutrient content of the foliage and the Yield Class, respectively, as the dependent variable. A multiple regression with Yield Class as the dependent variable and site factors, soil chemical properties, and the indicator values of the herbaceous vegetation as independent variables was calculated. The statistical procedure is described in HERZBERGER (1995).

3. Results

The relation between the nutrient content of the soil and the needles shows no trend in the case of N, a weak correlation for K and a somewhat closer relation for Ca. With respect to nutrient deficiency figure 1 shows that the demand of most stands can be met. Comparing the three nutrients, insufficient supply is more common in the case of N, whereas only single stands of our sample lack Ca and K. The general shape of the relation with the nutrient content in the needles and the forest soil is similar for Ca and K. The relation between the K and Ca content in the needles and either soil compartment is weak. A closer relation only exists between the Ca content in the forest floor and the needles because a high Ca content in the forest floor is a consequence of a high Ca content in the needles. Almost every K content in the needles is possible, even when the K content of the soil is low (Figure 1).

The relation between C:N ratio and Yield Class in figure 2 contradicts the assumption that there is an ideal C:N ratio especially favoring the growth rate of trees. Figure 2 also does not show a relationship between Yield Class and base saturation. A multiple linear regression showed that less than 25 % of the variability of the Yield Class can be explained by soil chemical properties. The indicator values for temperature, soil acidity and N availability of the herbaceous vegetation according to the classification of ELLENBERG (1979) explained 35 % of the variability and proved

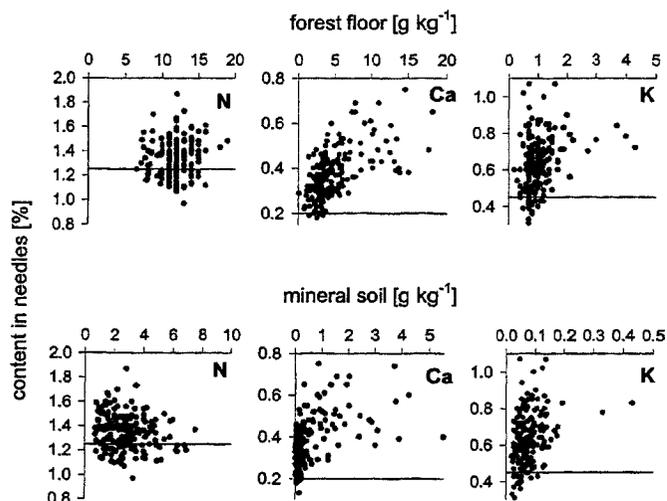


Figure 1: Scatterplot of nutrient content in the soil versus nutrient content in the needles of Norway spruce of the non-calcareous sites of the Austrian Forest Soil Survey. (upper panel) forest floor, (lower panel) mineral soil. The horizontal reference line is the threshold value for nutrient deficiency, according to HÜTTL (1986); note different scales on x-axis of upper and lower panel

Abbildung 1: Nährstoffgehalte im Boden und in den Fichtennadeln für karbonatfreie Standorte des Österreichischen Waldschaden-Beobachtungssystems. (obere Reihe) Auflagehumus, (untere Reihe) Mineralboden. Die horizontale Linie markiert den Schwellwert für Mangel des jeweiligen Nährstoffes nach HÜTTL (1986); Beachte unterschiedliche Skalierung der x-Achse in der oberen und unteren Reihe.

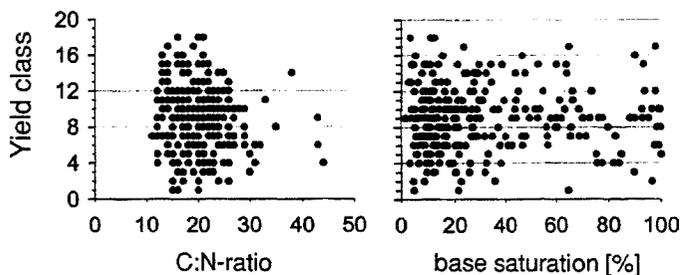


Figure 2: Scatterplot of the Yield Class versus integrated soil chemical parameters. (left): C:N ratio, (right): Base Saturation. Data are from the upper mineral soil (0–10 cm) of the non-calcareous sites of the Austrian Forest Soil Survey

Abbildung 2: Beziehung zwischen Ertragsklasse und bodenchemischen Parametern. (links): C : N-Verhältnis, (rechts) Basensättigung. Die Werte stammen aus dem obersten Mineralboden (Tiefenstufe 0–10 cm) der karbonatfreien Standorte der Österreichischen Waldboden-Zustandsinventur

therefore to be a better indicator for Yield Class than soil chemistry (HERZBERGER, 1995).

One identified shortcoming of the comparison of nutrient contents of soils and needles may be that the content *per se* is not an appropriate measure for that task. Even the most fertile piece of substrate with a tremendously high nutrient

content will certainly not suffice the nutrient demand of a forest stand, when it is available only in small quantities, *e.g.* due to the high rock content of the solum. It is certainly the pool size of plant available nutrients that matters, and not solely the content. For the sites of the Austrian Forest Monitoring System no estimates of the needle mass and only rough ones of the mass of the fine soil are available. The nutrient pools can therefore not be calculated from the available data. In order to investigate the relationship between nutrient pools in the soil and in the needles and leaves we used the published data of a recently finished EU-project, CANIF. The relations are displayed in figure 3. It can be seen that the relationship between the nutrient stock in the soil and in the foliage is weak. The unclear relation in figure 1 is therefore not caused by insufficient or inappropriate data but is rather a general property of forest ecosystems.

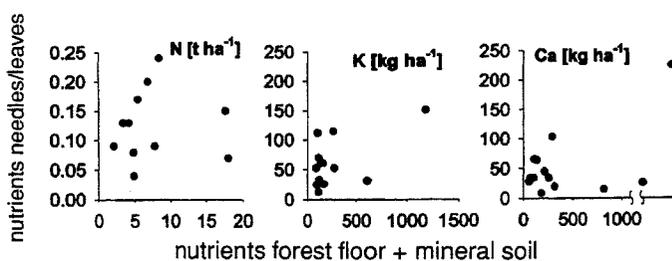


Figure 3: Relation between nutrient pools in the soil (total N, exchangeable K, Ca) and in the foliage. Source: Sites of the CANIF experiment (SCHULZE, 2000)

Abbildung 3: Beziehung zwischen Nährstoffvorräten im Boden (Gesamt-N, austauschbares K, Ca) und in den Nadeln (Gesamtgehalte). Quelle: Standorte des CANIF-Experiments (SCHULZE, 2000)

4. Discussion

The relationship between soil chemical properties, the nutrient content of the photosynthetic active tissue and the growth rate is generally understood as presented in figure 4: the higher the nutrient content of the needles and leaves, the higher the expected yield, and a close relation exists between the nutrient content in soils and needles/leaves (MENGEL and KIRKBY, 1987). This general pattern may apply for agricultural crops and on specific sites, where the competition between plants is regulated and where soils are kept fertile. The aboveground biomass of a forest as well as the soil are huge nutrient pools, but only a small fraction of the total pools is involved in annual nutrient transfer. Measurement of the total nutrient capital may not relate to the quantity available to plants (FISHER and BINKLEY, 2000).

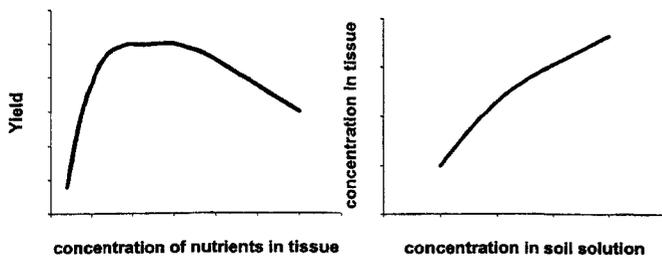


Figure 4: Relation between soil properties, nutrient content of needles and leaves and the growth rate. Left part: 'Mitscherlich function'; Rising nutrient content in photosynthetic active tissue translates into higher yield, until luxury consumption is reached; right part: relation between nutrients in the soil solution and the needles/leaves when other factors are held constant

Abbildung 4: Beziehung zwischen Bodeneigenschaften und Nährstoffgehalten von Nadeln/Blättern sowie der Wachstumsrate. Linke Kurve: 'Mitscherlich-Funktion'; Steigender Nährstoffgehalt im photosynthetisch aktiven Gewebe führt zu stärkerem Wachstum bis 'Luxus-Konsum' erreicht ist. Rechte Kurve: Beziehung zwischen der Nährstoffkonzentration in der Bodenlösung und jener in den Nadeln/Blättern bei Konstanz aller anderen Einflußgrößen

Trees as long-living organisms are pursuing a certain investment policy with their photosynthates. Maximum productivity during a short time span cannot be an appropriate goal, when a strategy of nutrient sequestration and allocation needs to apply for periods with favorable and unfavorable climatic conditions as well as for sites with high and low fertility. In order to ensure the success of individual trees for many decades, some investments in a life insurance are an appropriate strategy. Trees afford an extensive rooting system, and the internal storage of nutrients as their insurance policy. The cost of safety is paid by elevated respiration rates (KÖRNER, 1999). Productivity of a forest ecosystem is obviously a complex property that cannot solely be deducted from soil nutrient supply. It is the growth rate that drives the nutrient demand of a tree, and not the nutrient supply that controls the growth rate. Nutrient deficiencies can only be created if the growing conditions apart from soil chemical conditions at a given site allow for the development of a large needle mass, and the nutrient uptake cannot keep pace with the demand.

The linkage between nutrient content in soils and in the foliage of trees has been explored in several papers. Early on a summary by BAULE and FRICKER (1967) provided an overview over many forest experiments, where nutrient addition was a prerequisite for the establishment of a forest or where fertilization had greatly improved the growth rate of the forest. In typical forest amelioration experiments the

ultimate goal was to find a tool to increase the productivity of forest stands. The formation of a scientifically firm theoretical framework that would explain the observed results of the experiments in a strict scheme of cause and effect was literally not the aim. The researchers appreciated that much more complex experimental designs would be required to explain the results in great detail, but no such experiments were conducted. Proving the success of a certain stand treatment was a sufficient result for practical forestry. The major obstacle was, and still is, that mature forest stands are difficult to handle in experiments. Their size, both height and aerial extent, and the duration of their life cycle make meaningful experiments extremely difficult. Nevertheless, there are attempts to relate soil chemistry to tree growth. STERBA (1974) showed in an experiment in Upper Austria that soil chemical data explained only little of the observed stand growth. The linkage between soil chemistry, tree growth and tree nutrition was revisited within the research projects related to 'acid rain'. It was sought to corroborate the assumption that recently observed nutrient deficiencies in forests were related to declines in the soil nutrients. In these cases so as in a transect from Scandinavia to Italy only weak relations between forest soils and needles were found (ALDINGER, 1987; BAUER et al., 1997; HUNTINGTON et al., 1990; LANDMANN et al., 1995).

Our results show that the N nutrition status of spruce is more or less unrelated to the N supply from the soil (figure 1). Nitrogen is needed in higher plants in larger amounts than other nutrients except C, O, and H. It is an essential constituent of living cells, in particular of amino acids, proteins and nucleic acids. TAMM (1991) observed that there is often a close relationship between the amount of nitrogen that is available to roots and the total plant biomass. This conclusion cannot be derived from figure 3 and from the comprehensive data set in SCHULZE (2000) and JOHNSON and LINDBERG (1992). The total pool of nitrogen is obviously not a sensitive predictor of available nitrogen. Averaging over a large set of experiments, BINKLEY and HART (1989) have found that only 1 to 3 % of total N are available for uptake by trees each year. The pool of ammonium and nitrate, the N forms that are ultimately taken up by trees, is transformed quickly and turns over within hours to a few days (STARK and HART, 1997). This dynamic is certainly not captured by the measurement of total N. Still, the amount of nitrogen present in the soil has some indicator value for N dynamics. At sites with a high pool of N the rate of N cycling is generally higher than on N poor sites. Sites with a greater N capital have, on an annual basis, more N

available for trees and N from decaying organic matter becomes available quicker (PRESCOTT et al, 2000). The availability of mineral N is controlled by a complex set of physiological and geochemical factors (NADELHOFFER et al., 1984; SCAIFE, 1989). Summarizing it can be maintained that there is a relation between the N capital of the soil and the amount of N that plants will use. The linkage is, however, not straightforward and can therefore not be identified with scatterplots as shown in figures 1 and 3.

Cationic nutrients are absorbed on the exchange sites and form a readily available nutrient pool, but the composition of the exchange complex does not represent the cation-supply capacity of a soil. Cations removed from the exchange sites are often replenished from other sources. One has to keep in mind that the exchange complex reflects, like a template, numerous soil processes. Cation exchange itself is not a driving process, but is an integrating mirror of chemical weathering, water flux, microbial activity, and complex formation and dissolution. The pool of exchangeable bound cations is therefore a clearing house for the biogeochemical processes at a site, but it represents only a part of the available nutrients in a forest soil.

Calcium plays an important role for soil quality. In general it contributes the largest part of the base saturation and it is responsible for the physical structure of the soil. Calcium is recognized as a macro nutrient, because the Ca content of needles and leaves is usually high. On a molar basis the concentrations of K and Ca in needles of Norway spruce are similar. The high content of Ca mainly results from the high Ca concentrations in the soil solution, and not from an especially efficient specific uptake mechanism of the tree. Calcium is involved in a variety of physiological processes (MCLAUGHLIN and WIMMER, 1999). Although the Ca supply from the soil varies in a wide range, depending on the geological parent rock, Ca deficiency is a rare case. Numerous liming experiments have earned Ca the reputation that forest stands are very responsive to Ca addition. Closer inspection of the different experimental results have clearly demonstrated that the response was attributable to other, simultaneously achieved, soil improvements, such as raised pH-values and improved conditions for microbial processes (BLAGODATSKAYA and ANDERSON, 1999). The high availability of Ca in the soil versus the comparably low demand necessitates no peculiar Ca conservation processes. It is taken up passively, and is transported in the xylem sap in upward direction. Once Ca is deposited in older needles it cannot be mobilized (MENGEL and KIRKBY, 1987). Different from many other nutrients Ca is not re-translocated within the

tree and not leached from needles. Instead Ca accumulates. This behavior is reflected in figure 1. Among the three compared nutrients Ca shows the clearest relationship between concentrations in the soil and in the needles. Presently a debate is going on, how little Ca is required to maintain the growth rate of forests on a high level. This discussion is driven by the observation, that many soils in Central and Northern Europe and in the Eastern part of the United States lose Ca (PRIETZEL et al., 1997; HALLBÄCKEN and TAMM, 1986; HILDEBRAND et al, 1996; LIKENS et al., 1998; HUNTINGTON, 2000).

The potassium content of higher plants is generally high. It is an important electrolyte, it is of great importance for the water status, and it is required for enzyme activation (MENGEL and KIRKBY, 1987). Potassium is taken up at considerable rates because ionophores, located in membranes, allow for high rates of diffusion. The high permeability also allows for high rates of efflux of K. The chemical analyses of rainfall samples above and below a tree canopy show indeed, that considerable amounts of K are leached from the leaves and needles upon water passage through a tree canopy. This behavior is often phrased as 'potassium being held in an open cycle of leaching and uptake'. The source of K are primary minerals such as K-feldspars, biotite and muscovite, and secondary minerals such as illite (LIKENS et al., 1994). Figure 1 shows that K deficiency is a rare phenomenon in Austrian forest soils on non-carbonatic bedrock, even though the monovalent cation is prone to being leached from the mineral soil. At the cation exchange complex of mineral soils K can be specifically adsorbed in interlayers of clay minerals ('K-fixation'). The pools of K in the biomass and in the soil are high, compared to the annual flux rates, and pool sizes are of similar magnitude. Therefore a close relation between the K-content of the two compartments could be expected. Figure 1 shows a general pattern: at sites with high K contents in the soil the contents in the needles are high as well, and *vice versa*. However, even with very limited K resources the content in the needles can be high. One possibility would be specific uptake mechanisms that allow for the enrichment of plants with K. A second explanation is that the growth rate is slow on K poor sites and that for this reason only a small pool of tissue needs to be supplied with K. One corroboration is that the concentration of exchangeable K in the mineral soil proved to be the best single chemical parameter to explain yield-class ($R^2 = 0,199$; HERZBERGER, 1995). Even a small pool of available K would allow for luxury consumption.

The poor relation between cation supply of soils and the

nutrient pool in the biomass has puzzled many researchers. It was an enigma how trees can grow on extremely poor substrate and how vigorous growth can be maintained at infertile sites. It was clear that mycorrhizal fungi play an important role (BAREA, 1991; PERRY et al., 1992). SIMARD et al. (1997) have shown that the most vigorous trees of a forest stand can supply energy to other, less fortunate, individuals. However, these experiments can explain how photosynthates and energy can be allocated within a cohort of trees, but not how the general infertility of the site is overruled. In a series of weathering experiments JONGMANS et al. (1997) and VAN BREEMEN et al. (2000) have shown that mycorrhizal fungi excrete organic acids that dissolve rocks superficially. These 'rock-eating fungi' access nutrients at the primary source and do without the deviation of collecting nutrients from the exchange complex of the mineral soil. Another study (KOHLER et al., 2000) has shown that the soil skeleton, that is routinely excluded from chemical analysis, can bear large quantities of cationic nutrients. These nutrients go undetected if soils are investigated with standard analyses.

Maintaining the productivity of forests requires that nutrients are available and supplied at a certain rate. The annual cycling of nutrients between the soil and the trees and back includes only a tiny fraction of the nutrients that are present in the pools of the biomass and the soil. The size of the nutrient pools differs between elements. Also the dependence of the pool size with biological and geochemical processes varies. Forests utilize the nutrient resource cautiously. The annual flux and the pool size may vary independent from each other, depending if the site is at steady-state, or aggrading, or declining. As a consequence the soil nutrient pools are poor predictors of nutrient fluxes. Ultimately there maybe a tight relation between the diverse nutrient pools in a forest ecosystem. Due to the large number of interacting factors, a unifying concept of this relationship being valid over various site types is still missing. The approach of employing standard soil chemical analysis (pH, exchangeable cations, total content of C and N) can yield only a general overview, but can not represent the sought nutrient dynamics. The nutrient content of the foliage is undoubtedly a better indicator of tree nutrition. Nevertheless, soil chemical parameters are used in recommendations for amelioration fertilizations, simply because soil samples can be collected easily and at any time of the year, whereas sampling of the foliage requires harvesting of branches from the upper part of the trees and the sampling time is restricted to a short period within the dormant season. Both reasons make the collection of foliage samples not

impossible, but certainly more difficult than sampling soils. Above that there is a strong believe that soil chemical investigations allow insights into site conditions that are otherwise not accessible. Soil chemistry is considered to be an integrating parameter for the site conditions.

The Yield Class is a valid expression of site productivity resulting from an interplay of site properties, soil chemistry and climatic conditions. These factors are already partially reflected in the indicator values of the herbaceous vegetation. A multiple linear regression model, that includes these indicator values together with soil chemical properties and physiogeographic site properties, can explain 50 % of the variability of the Yield Class. Based on this result we conclude that a rigorous forest ecological assessment of site properties yields a reasonably valid estimation of site productivity, that can not be derived from soil chemical properties alone.

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