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Nutrient Contents of Spruce Needles from the Tyrolean Limestone Alps

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Key words: Nutrient concentrations, Bio-Indicator Grid, spruce, climatic factors, altitudinal zones.

Summary

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The nutrient concentrations in the needle samples of the Bio-Indicator Grid were used to evaluate the nutrient situation in the Northern Tyrolean Limestone Alps. The poor nitrogen supply, which was proved in the framework of the Austrian Bio-Indicator Grid, was found also in the Tyrolean Limestone Alps. In addition, a marked deterioration of the nutrient situation was observed during the period under investigation (1983-1992). It is assumed that the weather played an important part in this unfavourable development (lack of precipitation and significantly higher temperatures during the vegetation periods, particularly in 1992). The concentrations of phosphorus and potassium remained approximately the same; the calcium content increased. The most frequent types of deficencies were nitrogen, phosphorus, and NP deficiencies. In 1992, a marked decrease in the magnesium concentrations was found. Generally, the altitudinal zone between 1000 m and 1200 m showed the worst nutrient situation, which can also be seen from the fact that, during the last five years of investigation, samples from that zone had the lowest concentrations of N, P and Mg. .

So the nitrogen nutritiant situations of the needles of the area of Achenkirch was poor from the very beginning, it was not possible to show the significant deterioation of the situation of the Tyrolean Limestone Alps in the area of Achenkirch. A remarkable improvement of the nutrient situation was observed at the high-altitude sub-alpine sample plot (Schulterberg). As opposed to the results from the Limestone Alps, which did not show any significant changes regarding the supply with K and Ca during the same period, the K supply deteriorated in the area of the "Achenkich Altitude Profiles"; and the calcium supply improved remarkably. Different results were also obtained in respect of the Mg supply which, until 1990, improved in the Limestone Alps, but after that deteriorated clearly, while it remained almost at the same level in Achenkirch during the entire period. In both areas of assessment the mean P concentrations remained the same.

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Introduction

Nutrient supply is one of the most important criteria when describing the condition of conifers and needle analyses are an efficient method of evaluating the nutrient situation of conifer stands. In Austria, large-scale investigations regarding the supply of spruce with nutrient elements have been carried out since 1983 (STEFAN 1987, 1991, 1994); so it is possible to characterize and classify forest ecoregions 2.1 and 4.1 (Northern Tyrolean Limestone Alps) in respect of their nutrient situation and the alteration of the situation during the observation period. Additionally, the results can be compared to those of corresponding spruce needle analyses undertaken since 1983 in the framework of the ecosystematic project Achenkirch. This is a chance to check to what extent the results from the profiles of Achenkirch are in accordance with those from the all-Austrian monitoring grid.

Material and Method of Investigation

Material

The material used for the classification of the forest ecoregions was taken from spruce needle samples of three different grids (Basic Grid, Grid 83, Grid 85). Figure 1 shows the geographical location of these three grids in the Northern Tyrolean Limestone Alps.

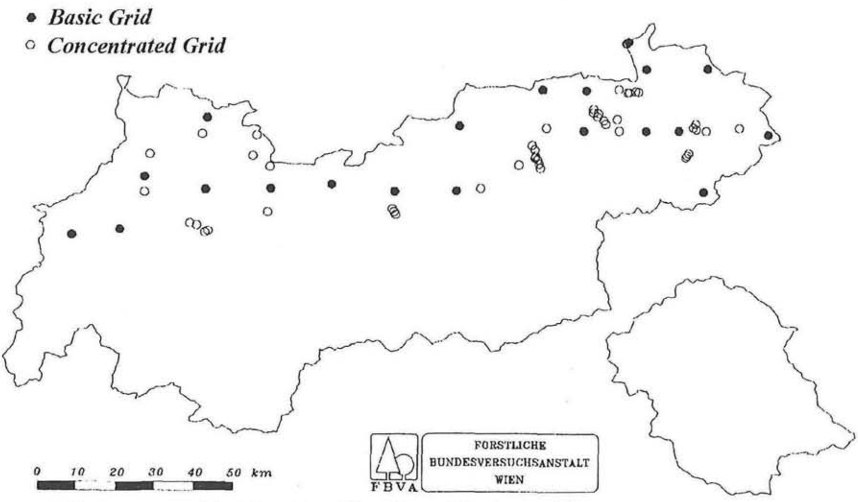

Fig. 1. Geographical location of the plots of the three grids.

The systematic Basic Grid, with a raster of 16x16 km (19 permanent sample plots), was established in 1983 and first sampled in that very year. From a topographic point of view, 32 additional plots were chosen in the same year (1983) which, together with the Basic Grid, formed Grid 83 (n=51). Finally, another 19 plots were added in 1985, so that a total of 70 plots (Grid 85) were sampled in the period from 1985 to 1992.

The branch samples were taken by the Tyrolean Landesforstdirektion according to the provisions of the "2nd Regulation Against Air Pollution Affecting Forests" ("Zweite Verordnung gegen forstschädliche Luftverunreinigungen", Federal Law Gazette 199/1984), each time in autumn from the two permanently marked trees of each sample plot. The data from the Bioindicator Grid discussed in this report was taken from needles from the period between 1983 and 1992 (Basic Grid, Grid 83) and from needles of the years 1985 - 1992 (Grid 85). The nutrient content of needles from the "Achenkirch Altitude Profiles" was studied on needles of the years between 1983 and 1993.

Methods and criteria of evaluation

The nitrogen content of the needle samples was determined by means of a volumetric analysis following Kjeldahl disintegration; after the (wet) disintegration the concentrations of the other major nutrients were determined photometrically or by means of atomic absorption spectroscopy.

The data from the chemical needle analyses of the current years needles (determined in the year of sampling) in respect of the nutrient supply of spruce were evaluated according to the values given in Table 1 (GUSSONE 1964).

Table 1. Guidelines for the classification of the nutrient supply according to GUSSONE 1964 (spruce - needle of the current year).

Nutrient supply	% N	% P	% K	% Ca	% Mg
insufficient/deficiency	≤ 1.30	≤ 0.11	≤ 0.33	≤ 0.10	≤ 0.07
inadequate	1.31 - 1.50	0.12 - 0.13	0.34 - 0.42	0.11 - 0.36	0.08 - 0.11
adequate	> 1.50	> 0.13	> 0.42	> 0.36	> 0.11

Moreover, the results of the nutrient ratios (STEFAN 1993, 1994) were also used to evaluate the nutrient situation, the ranges given in Table 2 (HÜTTL 1986) being considered harmonious.

Table 2. Harmonious ranges for the nutrient ratios according to HÜTTL 1986.

N/P	7.01	-	10.00
N/K	1.01	-	3.00
N/Ca	2.01	-	7.00
N/Mg	8.01	-	14.00
K/Ca	0.81	-	2.40
K/Mg	2.21	-	6.40
Ca/Mg	2.51	-	5.00

Results and Discussion

The nutrient situation was described by means of the ranges and mean values of the five major nutrient elements, the results of all three grids being considered in the evaluation. Changes which occurred in the course of the time were determined by calculating the percentage of insufficiently, inadequately, and adequately supplied material according to applicable criteria; also in this case the entire available data was included in the calculation. The nutritive ratios were calculated from the samples taken from Grid 85; the percentage shares of three ranges were presented, based on the harmonious range. For a more refined assessment of the nutrient situation, the percentages of those sample trees that were insufficiently supplied with one or several nutrient elements, respectively, were calculated. To prove annual variations and the changes that occurred in the course of the observation period, the calculations were always made for one year, each time evaluating the sample material of the Basic Grid and that of Grid 85.

To allow conclusions regarding effects of dilution or accumulation and the influence of weather particularities on the nutrient status, the *100-needle weights* and the *mean nutrient content* were determined (HEINSDORF 1966, HÖHNE 1968, HUNGER 1970a, STEFAN 1981, 1982). The 100-needle weights from the period between 1988 and 1992 were available for the evaluation.

To be able to answer the question of whether and how the nutrient supply varies with altitude, Grid 85 was used to show the results from five altitudinal zones. The sample plots below 600 m were combined to form one group; the altitudinal zones of 601-800 m, 801-1000 m, 1001-1200 m were described individually and all sample plots above 1200 m were again combined to one group. For these five altitudinal zones, the mean percentage of plots with insufficient supply of one nutrient element and the percentage of plots insufficiently supplied with several nutrients were calculated.

The influence of weather particularities on the nutrient content was illustrated using the examples of precipitation amounts and temperature. The data measured at four different meteorological centres in the Tyrolean Limestone Alps, published in the journal "Monatsberichte der Witterung in Österreich" (Monthly reports about the weather situation in Austria) by the Centre of Meteorology and Geodynamics, were compared to the long-time average. We calculated the per-year deviations of the precipitation amounts and temperatures from these mean values and the period from April to September was used as the basis of comparison. Detailed results were published by STEFAN & HERMAN 1995.

Mean values and ranges of nutrient concentrations between 1983 and 1992

The ranges and mean values of the nutrient concentrations were observed on the sample plots of the three grids. Apart from rare exceptions, the annual average of the sample material showed the same variations in respect of the major nutrients every year in all three collectives. Opposed to this, the individual Basic Grid values of those years frequently differed much less than the corresponding values from the two finer grids. This is due to the fact that much fewer samples had been taken from the Basic Grid than from the finer grids and that the plots had been more scattered in the investigation area.

Except for two years (1984-1985 and 1988-1989), the nitrogen means continuously decreased and in 1992 showed by far the lowest value of the 10 or 8 years under investigation. For phosphorus, the lowest means were measured in 1984 (grids investigated since 1983) and in 1988 (Grid 85), respectively. In the case of potassium the mean values varied relatively little; in all three collectives the lowest values were measured in 1990, but increased during the two succeeding years. The mean values for calcium in the three collectives were lowest in 1983 and 1986; from 1991 to 1992 they increased for all three grids by 28 % (Basic Grid) to 42 % (Grid 85), and all grids showed clear maxima in 1992. As opposed to this, the magnesium means decreased again during the last two years of the investigation after, compared to 1983 and 1984, they had strongly increased from 1985 onward compared to the results from the grids investigated since 1983.

Evaluation and classification of the nutrient content, changes in the course of time

According to the criteria established by GUSSONE 1964, the data from the sample material indicated in the first place insufficient nitrogen supply, followed by a phosphorus deficiency. In several years the needles also showed a minor potassium or magnesium deficiency. It is interesting to note that the nutrient situation deteriorated in the course of the investigation period. The percentage of Basic Grid plots showing a nitrogen deficiency was 21 % to 42 % between 1983 and 1989; then it rose to 47 %, 58 %, and, finally to 63 % in the three succeeding years. This negative development was observed also in the case of the finer grids where in the last year under investigation more than 60 % of the sample plots showed a nitrogen deficiency. Compared to 1985/86 when only about a quarter of the three grids had shown a nitrogen deficiency, the number of sample plots with such a deficiency on average more than doubled during the last two years under investigation. When evaluating the nutrient situation it is also remarkable that already in 1984 the nitrogen supply had been extremely poor compared to the year before and the succeeding two years. In 1984, also a very poor phosphorus supply was observed (47 % of the Basic Grid plots and 59 % of those of Grid 83 were insufficiently supplied) although for the other years the percentage of insufficiently supplied trees was only between 5 % and 16 % (Basic Grid) and 4 % and 28 % (Grid 83), respectively. The supply of the sample material with potassium and calcium never had to be classified as insufficient. For the finer grids, where only a maximum of one (Grid 83) or three (Grid 85) individual plots were insufficiently supplied with potassium between 1983 or 1985 and 1991, by 1992 the percentage of plots showing a potassium deficiency rose to 8, or 10, and the percentage of plots well-supplied with potassium sank to the lowest value calculated since the beginning of the investigation. Also the percentage of plots sufficiently supplied with magnesium decreased in 1992 to reach the lowest value ever observed; the decrease compared to the year before being, however, much more remarkable for magnesium than in the case of potassium.

Assessment of the nutrient situation by means of nutrient ratios

For the assessment of the nutrient situation the so-called "harmonious ranges" by HÜTTL 1986 (i.e. the amounts of nutrient elements needed for balanced nutrition, cf. Table 2) and the percentages of the nutritive ratios for three ranges were used. Seeing the 8 years under investigation, the N/P and Ca/Mg ratios on an average had the lowest percentage shares of sample plots in the harmonious range (61 % and 63 %, respectively), as compared to more than 85 % for the N/K, N/Ca, and K/Ca ratios. With one exception (N/P) all nutrient ratios had the lowest percentage of plots in the balanced range in 1992. The decrease from 1991 to 1992 was most significant in the case of N/Ca, but even for the other ratios was about 10 %.

Types of frequency and deficiency

Types of deficiency indicate the shortage of one or the simultaneous shortage of several nutrient elements. For the calculation of the percentages of plots insufficiently supplied with one or several nutrients the entire data bases was used.

It could be shown, that the nutrient situation deteriorated significantly in the course of the period under observation and that both the Basic Grid and Grid 85 suffered from the poorest nutrient supply in 1992. In the individual years from 1985 to 1991 between 42 % and 74 % of the plots of the Basic Grid and between 43 % and 71 % of the plots of Grid 85 had not shown any deficiency; in 1992 this was true for only 37 % of the Basic Grid plots and 27 % of those of Grid 85.

The data basis also illustrates that in the Basic Grid and in Grid 85 individual nitrogen deficiencies were the most frequent type of deficiency in nearly all years of investigation, followed in both grids by combined N/P deficiencies, while individual phosphorus deficiencies ranged only third. The negative development of the nutrient supply in recent years, illustrated in Figure 2, is also evident from the percentage shares of plots which never showed any deficiency during four-year periods.

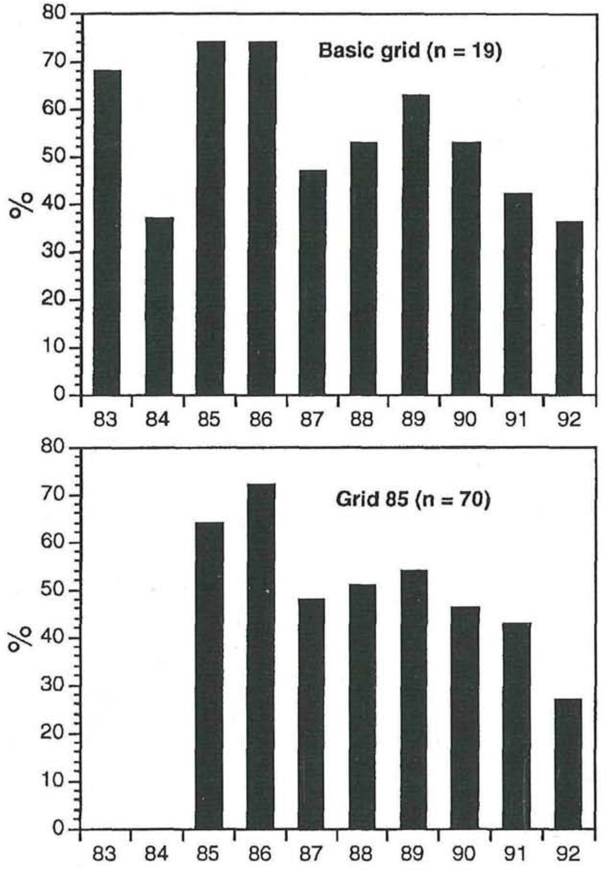

Fig. 2. Percentages of plots without any deficiency.

In the four-year period from 1985 to 1988, 37 % of the Basic Grid plots and 41 % of those of Grid 85 had never shown any deficiency; from 1989 to 1992 this was true only for one fifth of the sample plots. Between 1985 and 1992 more than half of the Basic Grid points and more than 40 % of the plots of Grid 85 showed deficiencies of at least one nutrient element in more than half of the eight-year period.

100-needle weights; nutrient content and weather conditions

As for 80 % of the plots of Grid 85 the 100-needle weights for all of the years from 1988 to 1992 were available, it was possible by using these and by calculating the respective nutrient content per 100 needles to study the question whether the reduced nutrient concentrations of 1992 had been a consequence of dilution or of weather peculiarities. The mean 100-needle weights varied only between 576 mg and 593 mg from 1989 to 1991, after they had increased by almost 20 % from 1988 to 1989. From 1991 to 1992 the mean 100-needle weight decreased dramatically by more than 40 %. The variation of the mean amounts of nitrogen, phosphorus, potassium, and magnesium per 100 needles between 1988 and 1992 corresponded to the variation of the mean 100-needle weights. Opposed to this, the mean amounts of calcium per 100 needles from 1989 to 1991 increased only slightly compared to 1988; and with a 23 % reduction between 1991 and 1992 decreased only about half as much as the other elements and the 100-needle weights, which caused a clear increase of the percentage share of calcium from 1991 to 1992. These results allow the conclusion that the reduced nutrient concentrations of 1992 were not due to dilution, but to weather-related variations of the nutrient supply which has a few times been referred to in literature (WEHRMANN 1961, HEINSDORF 1966, 1973, HUNGER 1970b, BERGMANN 1983, SCHMIDT 1985). The results from four meteorological stations in the Tyrolean Limestone Alps confirm this statement (Table 3). The amounts of precipitation, given in percentage of the long-term average, always showed a deficit at the station of Landeck, which was particularly marked in 1991 and 1992. Also at Reutte the annual amounts of precipitation decreased and were lowest in 1992. At the meteorological station of Innsbruck, too, the lowest amount of precipitation measured during the 10-year observation period of was determined in 1992 although the year before the amounts of precipitation had been markedly higher compared to the long-term average both in Innsbruck and at the station of Kufstein. Even more, compared to the other three stations the amounts of precipitation observed in Kufstein were in some years above the long-term average. Generally one can say that deficits were observed at all four stations in 1984, 1986, 1988, 1990, and 1992, and that (except for Kufstein 1986) 1992 was the year when the amount of precipitation was lowest. If one takes into consideration that the investigation was based on the data from the period between April and September, which is particularly important for the growth, the results clearly indicate that weather conditions influence the development of trees.

The influence of natural stress factors was even intensified by the fact that, during the summer months of 1992, temperatures were higher than in earlier years of the investigation. Also, literature mostly refers to the modification of nutrient situations through extreme weather conditions during individual years, while the extreme conditions lasted for several years in that case, so that the trees could not recover in the meantime. Probably the marked decrease of the nitrogen and magnesium concentrations, the significant increase of the calcium content, the reduction of the number of plots not showing any deficiency as well as the markedly

Table 3. Precipitation in % of the long-term average and deviations of temperature from the long-term average (each time from April to September).

Station	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
	Amounts of precipitation (in % of the long-term average)									
Reutte	102	90	104	89	91	87	91	86	87	67
Landeck	78	76	99	87	85	85	82	87	62	64
Innsbruck	108	93	111	94	111	94	106	90	110	80
Kufstein	105	93	102	78	96	80	92	85	112	80
	Deviations of the temperatures from the long-term average (°C)									
Reutte	1.2	-1.0	0.0	0.0	0.1	0.6	0.1	-0.1	-0.2	1.3
Landeck	1.0	-0.8	0.3	0.6	0.3	0.9	0.1	0.4	0.4	1.7
Innsbruck	1.2	-0.9	0.2	0.5	-0.1	0.7	-0.2	0.3	0.1	1.7
Kufstein	1.1	-0.9	0.3	0.4	0.3	0.7	0.0	0.2	0.1	1.8

lower 100-needle weights and the nutrient content per 100 needles from 1991 to 1992 were due to special weather conditions. This assumption seems even more probable as the reductions were less marked at higher locations, a phenomenon which might be explained by the lower amount of precipitation in Alpine valleys; at the meteorological stations in the valleys the amounts of precipitation decreased more significantly than at higher altitudes.

Nutrient supply in different altitudinal zones

To be able to decide whether and to what degree the supply with nutrients depends on altitude, the classifications were combined with the respective altitudinal zones. Table 4 shows the mean percentages of the sample plots indicating either no deficiency at all or a deficiency of one or several nutrient elements (types of deficiency). Table 4 also shows that at least up to an altitude of 1200 m there was always a clear correlation between altitude and nutrient supply.

Table 4. Mean perentages of the different types of deficiency and of plots without any deficiency in the five altitudinal zones (Grid 85).

Altitudinal zone	No deficiency	Type of deficiency							
		N	P	K	Mg	NP	NK	NPK	PKMg
< 600 m	60.4	9.4	12.5	5.2	-	10.4	1.0	-	1.0
601- 800 m	62.5	16.7	5.8	0.8	-	14.2	-	-	-
801-1000 m	51.4	30.6	0.7	0.7	0.7	12.5	0.7	2.8	-
1001-1200 m	31.3	33.9	2.7	-	-	26.8	-	5.4	-
>1200 m.	47.7	-	-	-	2.3	-	-	-	

The mean percentages of plots without any deficiency were 60 % and 63 %, respectively, in the two altitudinal zones up to 800 m, but only 51 % in the next zone, and 31 % at the altitudinal zone between 1001 m and 1200 m, which was the lowest value of all altitudinal zones. Above 1200 m the mean percentages of plots without deficiency would rise significantly to reach about 48 %. Opposed to this, the mean share of plots showing a nitrogen deficiency would continuously rise with increasing altitude. In the two zones of lowest altitude the corresponding values were only 9 % and 17 %, respectively; the corresponding values in the next two altitudinal zones (up to 1200 m) were about 31 and 34 %, respectively, and approximately 50 % at altitudes above 1200 m. For the second-most frequent deficiency, the combined nitrogen and phosphorus shortage, the mean share of plots located in the three altitudinal zones up to 1000 m was between 10 % and 14 % and with about 27 % was highest between 1000 m and 1200 m. In the altitudinal zone above 1200 m the share of this type of deficiency (simultaneous N/P deficiency) was lowest. Considering all results, the altitudinal zone of 1001 m-1200 m if compared to the other altitudinal zones was the one which, based on the mean values of 1985-1992, was most frequently insufficiently supplied with nutrients. Here also the 1988-1992 average of the 100-needle weight and the amounts of nitrogen, phosphorus and potassium per 100 needles were the lowest of all 5 altitudinal zones.

Results from the investigation area of Achenkirch and comparison of these results with data from the Tyrolean Limestone Alps (based on mean values)

In the frame of the Achenkirch altitudinal profiles nutrient analyses on spruce needles have been carried out since 1983. The values discussed below are from different time scales (for more details see STEFAN & HERMAN 1995).

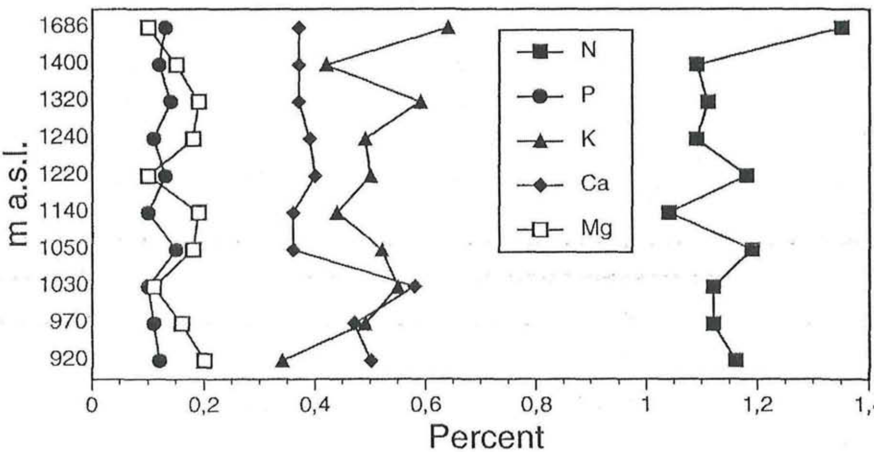

Fig. 3. Grand average of the nutrient content of the individual sample plots (1983-1993 and 1991-1993).

Altitudinal Correlation

Figure 3 shows that the nitrogen supply was with one exception (Schulterberg, 1686 m) always insufficient; as for the Limestone Alps, the area worst supplied with nitrogen was again the zone at about 1100 m. At 1686 m the nutrient situation in respect of nitrogen improved, but still was not adequate and the improved nutrient situation might have been because the stands had not been pruned. The phosphorus supply was adequate during the entire period under investigation and did not show any altitudinal variations. The potassium values differed strongly and were mostly classified as inadequate or adequate. The supply with calcium varied greatly at altitudes up to 1000 m, but from this zone onward proved to be uniform. The magnesium supply was in most cases adequate, but in some years, especially at the highest sample plot, had to be classified as inadequate.

Annual Variation

Figure 4 shows that the calcium supply improved during the observation period, while that of potassium deteriorated significantly until 1986 (although it was still sufficient), but only slightly from 1986 onward.

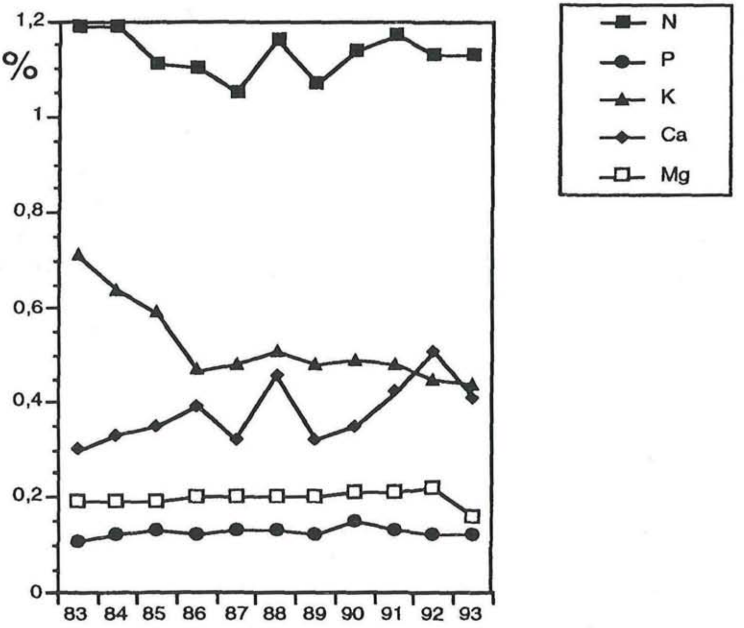

Fig. 4. Grand averages of the nutrient concentrations (%) of the sample plots in the years of investigation (1983-1993).

The sufficient supply with magnesium did not change; that of phosphorus varied between sufficient and insufficient, but did not show any extreme changes.

The supply with nitrogen was subjected to more marked variations; it was worst in 1987, improved slightly during the succeeding years, however without reaching the nutrient status of 1983 and 1984. It should be noted that all those changes occurred within the range of insufficient supply. It is remarkable also that in the classification of the sulphur concentrations the year 1987 showed extraordinarily high percentages for the altitudinal zones 3 and 4 (which indicates air pollution input, or even strong air pollution input) as compared to the percentages determined for the preceding and immediately succeeding years.

In the assessment of the nutrient supply on the basis of the nutrient ratios the example of the N/P ratio of the Christlum Altitude Profile showed a certain improvement of the nutrient situation. As shown in Table 5 the range assumed to be harmonious (7.01 - 10.0; HÜTTL 1986) was less frequently exceeded or not reached from 1989 onward.

Table 5. Ranges of the N/P ratio at the Christlum Altitude Profile. Observation period 1983-1993
Bold: Plots exceeding or falling short of the harmonious range in % of the total amount of samples.

Plot number	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	**12.4**	-	8.5	7.9	8.8	9.9	9.0	**6.9**	8.2	7.3	7.9
2	8.8	-	7.8	8.2	7.6	7.8	**6.7**	**6.2**	.8,2	8.2	8.1
3	8.7	-	**10.4**	**10.1**	9.1	**14.7**	9.8	9.3	.9,5	**10.1**	9.4
4	**11.6**	-	**10.4**	**10.3**	9.2	**10.4**	9.8	9.0	**10.1**	9.5	**10.3**
5	**10.8**	-	**6.9**	**11.2**	7.1	**5.7**	7.8	**6.3**	9.0	8.9	8.1
6	**11.9**	-	**10.4**	**10.8**	9.5	**11.0**	9.7	9.2	9.1	9.5	9.7

Opposed to this, the nutrient situation in respect of the N/P ratio was mostly not harmonious (due to excessive values) from 1983 to 1988, especially not on plots located near a valley and up to about 1200 m a.s.l. Also, this way of evaluation shows extraordinary results for 1987. With regard to the N/P ratio the needles of the sample trees of all sample plots were in the harmonious range in 1987.

The conclusions are, according to the results of the chemical needle analyses of spruce undertaken in the Austrian Bio-Indicator Grid the nutrient situation of the Tyrolean Limestone Alps in the period from 1983 to 1992 as follows:

- The most significant result of the analyses was that, in the course of the 10 years, a marked reduction of the nitrogen content of the needles was observed. Unlike that, the phosphorus and potassium concentrations but for one exception remained about the same. The mean magnesium values increased until 1990; after that, they decreased significantly, particularly in 1992. Opposed to this, the calcium concentrations increased in 1992.

- A classification of the relevant nutrient concentrations of the individual sample plots indicated that the most frequent type of deficiency was the practically continuously increasing insufficient nitrogen supply (≤ 1.30 % N), followed by the insufficient supply with phosphorus (≤ 0.11 % P). In rare individual cases potassium and magnesium deficiencies were observed (≤ 0.33 % K, ≤ 0.07 % Mg).
- Apart from individual nitrogen or phosphorus deficiencies, frequent simultaneous deficiencies of those two elements were also observed.
- The percentage of plots without any deficiency varied rather strongly between the individual years of investigations; from 1989 onward, the percentage of such plots decreased continuously, which means that the nutrient situation deteriorated.
- Also, a deterioration of the nutrient supply with increasing altitude was proved. When the results were related to 5 altitudinal zones, the zone between 1001 m and 1200 m according to the results of the samples from Grid 85 showed the most unfavourable nutrient supply. On an average of the last 5 years of the investigation, this altitudinal zone also showed the lowest 100-needle weights and the lowest amounts of nitrogen, phosphorus, and potassium per 100 needles.
- Similar to the results from the Bio-Indicator Grid plots in the Northern Tyrolean Limestone Alps, the nitrogen supply was insufficient also in the Achenkirch Altitude Profiles, with the most unfavourable nutrient situation in the "critical" altitudinal zone of 1100 m. The nitrogen supply was better in the higher regions of the subalpine area, where the magnesium supply proved to be more insufficient.
- It can be assumed that the weather conditions, illustrated by means of the deviations of total precipitation and temperatures from the long-term average of the period from April to September, significantly contributed to the most unfavourable development of the nutrient situation, particularly to the changes from 1991 to 1992.

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