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WŁADYSŁAW CHAŁUPKA

Effect of mineral fertilisation on the content of reproductive organs in the litter dropped by a Norway spruce (*Picea abies* (L.) Karst.) canopy*

INTRODUCTION

Knowledge of the conditions in which the process of generative reproduction is taking place in forest trees is necessary as a basis for any practical activity aimed at the intensification of the production of high quality seeds. Forest trees are characterized by a natural periodicity of seed crops. This phenomenon is unsatisfactory from the point of view of planned afforestations and requires counteraction by the forester. Its ill effects need to be minimized either by an increase in the seed production during seed crop years and then their long term storage or by a stimulation of regular seed production every year, or at least a reduction of the number of years between good crops.

Search for satisfactory methods of flower stimulation has to be preceded by studies about the mutual relationships between generative reproduction and a complex of internal and external factors. This justifies the undertaking of studies aiming at an estimation of the relation between flowering and seed crops in Norway spruce (*Picea abies*) and the mineral fertilisation of the soil. In the present study the soil subjected to fertilisation represented a uniform forest site type, and an effort was made to select one that would be optimal for the species. It was assumed that an optimal soil would be in a biological equilibrium, with an adequate supply of mineral elements for good growth of the trees. Introduction of considerable quantities of mineral elements into such a soil should disturb this equilibrium and in the mature trees this might become manifest in the intensification of generative reproduction.

LITERATURE REVIEW

The literature on the effect of mineral fertilisation on the flowering of various tree species is very extensive, thus in the present review only the results concerning Norway spruce will be summarized. Those intere-

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sted in the problem relative to other tree species should consult review papers on the effect of external factors on flowering in trees (M a t t h e w s 1963, F a u l k n e r 1966, J a c k s o n and S w e e t 1972, P u r i t c h 1972, B l e y m ü l l e r 1973).

Soil is a very important component of the forest site, and its richness has an effect on the seed crops. In years of good cone crops trees utilize considerable quantities of mineral nutrients therby depleting the mineral content of the soil. According to M o l č a n o v (1961) this could be one of the factors responsible for the periodicity of seed crops.

The intensity of cone crops in spruce varies with the forest site type. Trees growing on the most productive site types fruit most abundantly (M o l č a n o v 1950). A similar relationship was reported in Finland for Scots pine by S a r v a s (1962). He has established that on three forest site types with increasing fertility — *Calluna*, *Vaccinium* and *Myrtillus* — the seed crop ratios are 1 : 2 : 3. According to B a r a b i n (1968, 1969) such a relationship occurs only in the years of poor crops while in a year of abundant crop spruce stands yield seeds with equal intensities, regardless of the site type. This is confirmed by the results of pot experiments. In the spring of 1966 S k o k l e f a l d (1970) has subjected a mature spruce stand growing in southern Norway to a fertilisation with nitrogen and phosphorus using 200 kg N per ha and 30 kg P per ha. This fertilisation has not had any effect on the number of cones nor on the number of seeds collected in 1967, which was a good seed year in Scandinavia.

M ä l k ö n e n (1971) fertilised individual 90 year old spruce trees in Finland on *Myrtillus* site type. He has used various doses of NPK fertilizers, applying them three times, in the years 1964, 1966 and 1968. The maximal doses of individual fertilizers were 243 kg N per ha, 139 P_2O_5 per ha and 200 kg K_2O per ha. When analysing the results he has used multiple correlation techniques including besides the fertilizer treatments such factors as tree diameter, annual increment in basal area and the content of nitrogen, phosphorus and potassium in the needles of the fertilised trees. An analysis of cone collection made in the year of abundant crop has shown that the number of cones was dependent primarily on the diameter of the trees and on the percentage content of potassium and nitrogen in the dry weight of needles. The effect of fertilisation on the abundance of cone crops was not observed.

In a year of poor crops (1969) the number of cones was dependent on the diameter of the trees, on the basal area increment in the given year and on the coefficient of competition (a value determining the mutual relationships between the fertilised trees and their neighbours). On the basis of these results Mälkönen claims that appropriate mineral fertilisation may to a certain degree increase the cone crop in the year of abundant flowering and its positive effect is not observable in non-crop years.

A similar method of fertilising individual trees has been employed by Nebe (1973). He has performed a nitrogen-potassium fertilisation in the years 1963, 1966 and 1970 in a 97-year old spruce stand, on a poor quartz soil. The total doses of the fertilizers were 360 kg N per ha and 150 kg K_2O per ha. Nitrogen fertilisation in the form of ammonium and calcium nitrate has resulted in a six-fold increase in the crop of the cones in 1971.

Less obvious effects have been caused by fertilisation with ammonium and calcium nitrate made in a 100-years old stand on a brown forest soil (Heinze and Wagner 1973). Three times doses of 100 kg N ha in three succesive years — 1969, 1970 and 1971 — have resulted in an increase in the seed crop yet the increase was not statistically significant.

Mineral fertilisation performed in a 60 years old spruce stand on site class II in Rumania has shown that also phosphorus and potassium may have a positive influence on the production of cones by increasing the number of trees that flowered (Enescu et al. 1973).

Besides its influence on the number of cones and seeds produced the effect of mineral fertilisation on the quality of seeds has also been investigated. Skoklefald (1970) has found a significant increase in 1000 seed weight (full and empty together) under the influence of nitrogen and phosphorus fertilisation. Also the weight of 1000 full seeds has increased under the influence of fertilisation, however this increase was not significant. Skoklefald has also established that the seedlings from seeds collected from fertilised trees were bigger and weighed more.

A drop in the weight of 1000 seeds and an increase in the proportion of empty seeds has been observed in the experiment of Heinze and Wagner (1973), but this was not a statistically significant tendency.

Mineral fertilisation in the experiment of Skoklefald (1970) has also had a significant effect on the length and weight of cones, while Mälkönen (1971) and Heinze and Wagner (1973) have not found this relationship.

The results summarized above contradict each other, sometimes to a considerable extent. Presumably this is caused by differences in site conditions, in which the experiments were conducted and by differences in doses of fertilizers used. One should also mention the fact that there have been very few reports on the effects of mineral fertilisation on spruce, which makes it difficult to draw any general conclusion.

In spite of these inadequacies of the available data it can be said that mineral fertilisation, particularily nitrogen fertilisation may have a positive effect not only on the size of the cone and seed crop but it can also improve the quality of the crop. On the other hand it was not found that mineral fertilisation could affect the periodicity of cone and seed crops in Norway spruce.

MATERIALS AND METHODS

THE EXPERIMENTAL AREA

The experiment was established in the massif of the largest mountain of Silesian Beskid, namely Skrzyczne (1250 m elev.). According to Mroczkiewicz (1952) this place lies in the Carpathian Zone, region of Silesian Beskid and the Babia Góra range. Administratively the stand lies in the old Forest District Szczyrk (presently in For. Dist. Bielsko), Forest Range Salmopol, compt. 155c. The old Forest District Szczyrk lies in the montane climatic zone. The mean annual values for some of the climatic factors are as follows, based on the nearest meteorological station on Klimczok (elev. 1010 m): Temperature — +4.7°C; Temp. amplitude — 22.1°C; Insolation (from Kubalonka met. sta.) — 1526.6 hrs; Precipitation — 979.9 mm; Days with frost — 136; Days with snow — 134; Prevailing wind direction S and SW. The vegetative period in nearby Wisła is 205 days getting below 200 days in upper reaches of the mountains.

The basic data about the experimental area as obtained from a working plan made for Forest District Szczyrk in 1964 is as follows: Longitude E — 18°59′, Latitude N — 49°41′; Elevation in m — 780; Average age — 75; Average height in m — 26; Average diameter in cm — 33; Average stocking, m³/ha — 540; Stocking — 1.0; Average no. of trees per ha — 547; Site class — II Quality — 2. The stand

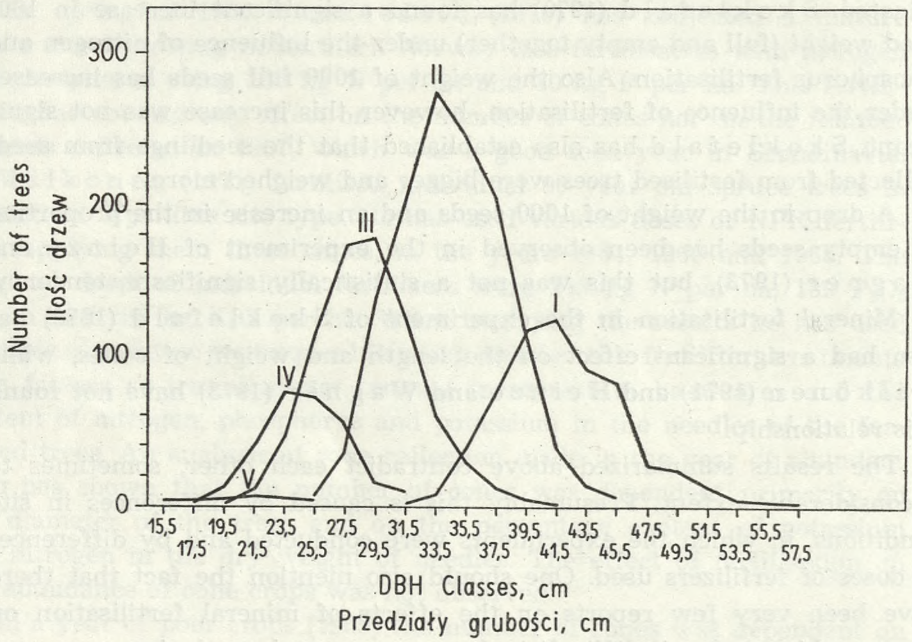

Fig. 1. Structure of tree diameters in biological classes of Kraft

Ryc. 1. Struktura grubości drzew w klasach biologicznych Krafta

lies on a steep slope with a southwestern exposition. The forest site type has been classed as a mountain forest on a brown forest soil, acid, medium skeletal, with the participation of a loamy fraction. The ground vegetation in the stand is very poor — in places *Polytrichum sp.* and *Calamagrostis sp.* occur. Most probably the stand arose from a plantation of unknown seeds. It is composed almost entirely of spruce with a sporadic occurence of *Abies alba* and *Fagus silvatica*. The canopy is moderately dense, in places compact or disjointed. The structure of stem diameters in the biological classes of Kraft are presented in Fig. 1 on the basis of diameter measurements made in the autumn of 1974.

In the spring of 1971 in this stand an experimental area was established (Fig. 2) comprising 54 square plots, each 0.1 ha in area. Each plot has been designated in the field by oak poles with labels fixed to them. The labels contained the basic

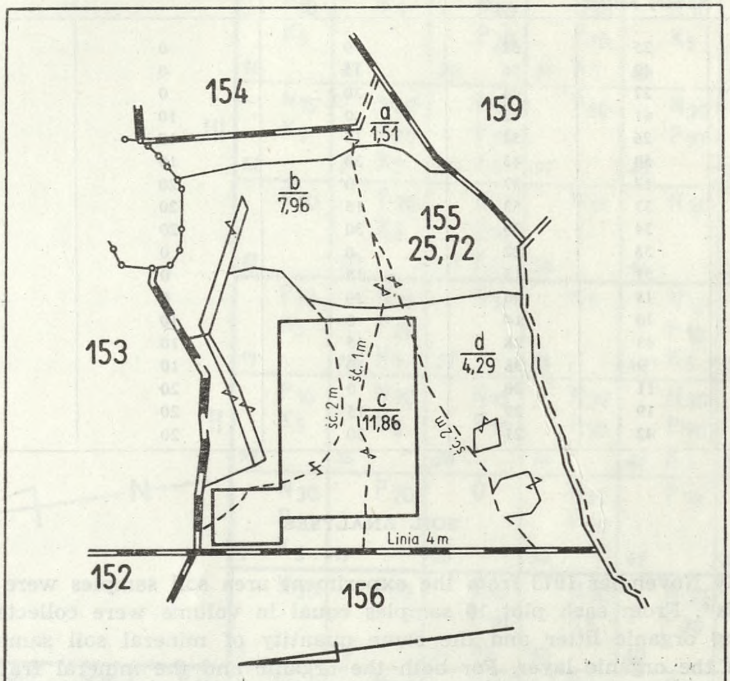

Fig. 2. Localisation of the experimental area in the spruce stand
Ryc. 2. Lokalizacja powierzchni doświadczalnej w drzewostanie

data about the plots, i.e. the replicate and the doses of fertilizers applied. In the centre of each plot, on the ground a 1 m² catchment box was positioned. The box consisted of tin sides, 20 cm high and a bottom made of dense fabric of plastic threds, which was permeable to water. The catchment boxes were numbered consecutively from 1 to 54.

FERTILIZER TREATMENT

Three mineral fertilizers were applied: ammonium nitrate (34,5% N) at three levels, powdery superphosphate (18% P_2O_5) at three levels and potassium salt (60% K_2O) in two doses, employing all possible combinations of these fertilizers. Table 1 gives the used doses of the fertilizers for the individual plots.

There were 18 fertilizer combinations in all distributed randomly between 18 plots within each of three blocks (replicates). The area has been divided into blocks more or less contour-wise, assuming the greatest variability gradient will be along the slope (Fig. 3). The fertilizers were distributed on the 5th and 7th of June 1971.

Table 1

Doses of fertilizers applied to the spruce stand

Dawki nawozów użyte w doświadczeniu

Replicates Powtórzenia			Fertilizers in kg per 0.1 ha Nawozy w kg/10 arów		
I	II	III	Nitrogen Azot	Phosphorus Fosfor	Potassium Potas
Plot numbers Numery poletek					
39	25	52	0	0	0
4	49	36	15	0	0
8	27	44	30	0	0
6	41	12	0	10	0
7	26	54	15	10	0
15	50	45	30	10	0
16	17	37	0	20	0
47	33	53	15	20	0
40	34	30	30	20	0
1	35	22	0	0	5
31	51	13	15	0	5
32	18	46	30	0	5
48	10	14	0	10	5
5	43	28	15	10	5
24	9	38	30	10	5
23	11	20	0	20	5
3	19	29	15	20	5
2	42	21	30	20	5

SOIL ANALYSES

In early November 1973 from the experiment area soil samples were collected for analysis *. From each plot 10 samples equal in volume were collected of the decomposing organic litter and the same quantity of mineral soil samples from underneath the organic layer. For both the organic and the mineral fractions the following analyses were made: 1. combustion losses as % of dry weight, 2. hygroscopic water content as % of dry weight, 3. exchangeable pH in KCl, 4. active pH in H_2O, 5. carbon content as % of dry weight, 6. nitrogen content as % of dry weight, 7. C/N ratio, 8. content of K_2O in mg per 100 g of soil, 9. content of P_2O_5 in mg per 100 g of soil.

Furthermore the following analyses were made for the mineral samples only: 10. sorption capacity in miliequivalents, 11. content of K^+ ions in miliequivalents, 12. content of Na^+ ions in miliequivalents, 13. content of Mg^{++} ions in miliequivalents, 14. content of Ca^{++} ions in miliequivalents.

COLLECTION OF DATA ON GROWTH

In October 1974, that is after the termination of the fourth vegetative season from the time of fertilisation, in the studied stand samples of wood were collected for analyses of growth increments. The samples were collected with a Pressler borer, from 8 closest trees to the catchment box in each plot. The trees surround the catchment box and the sample was always taken from the side of the tree facing the catchment box, thus a considerable diversity of the orientation of the

* The analyses were conducted by Doc. Dr. Wojciech Dzięciołowski from the Agricultural Academy in Poznań.

samples relative to cardinal directions was obtained. The trees were bored only to a certain depth in order to obtain data on the growth over the last 20 - 30 years. On the collected samples (wood cylinders) the thickness of the annual increments and of the late and early wood were measured. The mean annual girth increments were compared between the plots by the variance analysis. Similarily the proportion of the late wood was analysed.

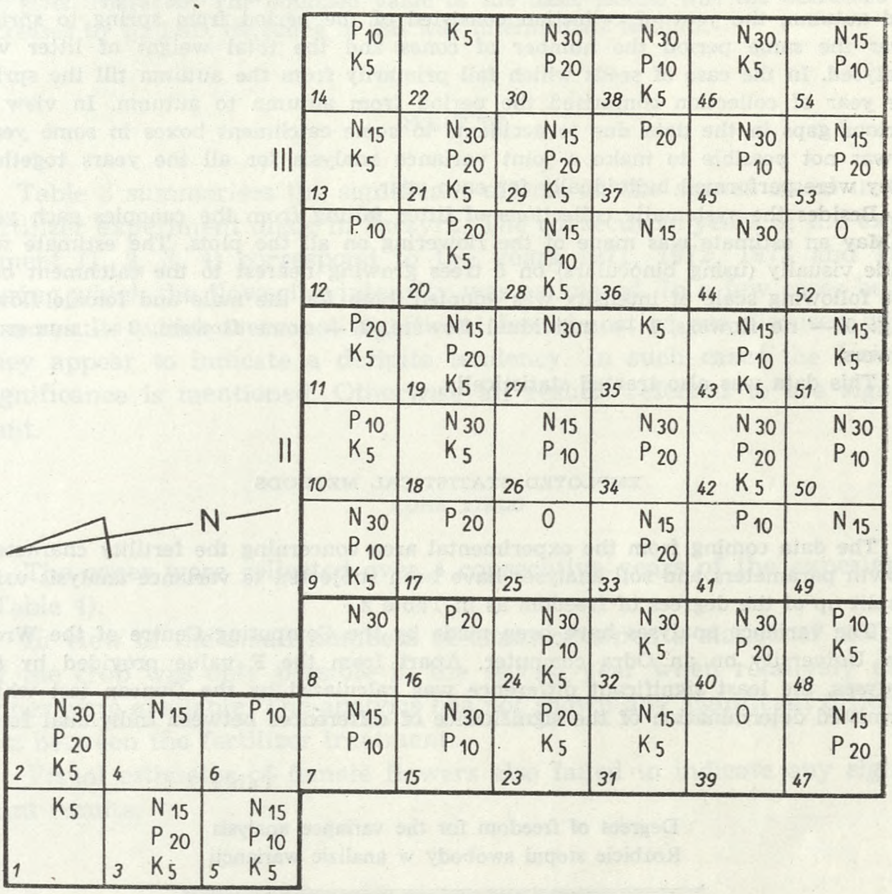

Fig. 3. Distribution of replicates and fertilizer combinations on the experimental area

Ryc. 3. Rozmieszczenie powtórzeń i kombinacji nawozowych na powierzchni doświadczalnej

In 1973 from each plot samples of secondary bark (primarily pholem and cambium) were collected using an increment borer. In these samples the content of nitrogen, phosphorus, potassium and sodium were analysed and the results treated by the variance analysis.

COLLECTION OF DATA ON SEXUAL REPRODUCTION

The litter falling into the catchment boxes was collected twice during a year, in the spring (April or May), and in the autumn (October or November). The first collection was made in April 1972 and the last in April 1975. The collected litter was dried in cloth bags at a temperature of 105°C for one day and weighed. From the dried litter the remains of male catkins, seeds and cones were selected out. In this way the following characters were obtained for statistical analysis: 1. number of cones, 2. number of male catkins, 3. number of seeds, 4. weight of 1000 seeds, 5. total dry weight of the litter.

These characters have been analysed on yearly basis, combining the litter collections. In the case of the male catkins which fall primarily between spring and autumn, the year of collection consisted of the period from spring to spring. Over the same period the number of cones and the total weight of litter was analysed. In the case of seeds which fall primarily from the autumn till the spring the year of collection comprised the period from autumn to autumn. In view of various gaps in the data due to accidents to some catchment boxes in some years it was not possible to make a joint variance analysis for all the years together. They were performed individually for each year.

Besides the systematic collections of litter falling from the canopies each year in May an estimate was made of the flowering on all the plots. The estimate was made visually (using binoculars) on 5 trees growing nearest to the catchment box. The following scale of intensity was adopted, both for the male and female flowering: 0 — no flowers, 1 — individual flowers, 2 — some flowers, 3 — numerous flowers.

This data was also treated statistically.

EMPLOYED STATISTICAL METHODS

The data coming from the experimental area concerning the fertility characters, growth parameters and soil analyses have been subjected to variance analysis using a split up of the degrees of freedom as in Table 2.

The variance analyses have been made by the Computing Centre of the Wrocław University on an Odra computer. Apart from the F value provided by the analyses, the least significant difference was calculated by the Duncan test which permitted determination of the significance of differences between individual ferti-

Table 2

Degrees of freedom for the variance analysis
Rozbicie stopni swobody w analizie wariancji

Source of variance Źródło zmienności	Degrees of freedom Stopnie swobody
Fertilizers Nawozy	17
N	2
P	2
K	1
N×P	4
N×K	2
P×K	2
N×P×K	4
Replicates (blocks) Powtórzenia (bloki)	2
Residual (error) Reszta (błąd)	34
Total Ogółem	53

lizer variants. The critical values of $F_{0.05}$ and $F_{0.01}$ have been obtained from the tables of Snedecor for the appropriate degrees of freedom.

Significant differences of all variance analyses have been presented in the from of graphs. When interpreting interactions occasionally the method of constructing contour isoline diagrams was employed. The value of the basic isoline was constructed by adding the least significant difference (LSD) to the lowest value for the given character. The obtained value of the basic isoline was the decreased or increased by 1/2 LSD, obtaining in this way intermediate isolines.

RESULTS

Table 3 summarises the significant effects on the spruce stand in the fertilizer experiment made in Szczyrk. The consecutive years of the experiment (1, 2, 3, 4) correspond to the years 1971, 1972, 1973 and 1974 during which the flowering intensity was estimated. In a few cases below also results which were not significant but almost so are discused when they appear to indicate a definite tendency. In such cases the lack of significance is mentioned. Otherwise all results referred to are significant.

CONE YIELD

The cones were collected over 4 consecutive years of the experiment (Table 4).

In view of the small numbers of cones obtained a statistical analysis of the crop was only possible in the second year when relatively more cones were available. The analysis has not shown any significant differences between the fertilizer treatment.

Visual estimates of female flowers also failed to indicate any significant results.

MALE CATKINS COLLECTED

The remains of male catkins have also been collected over 4 years (Table 5) and the data analysed separately for each year. The mineral fertilisation has had an effect on the number of falling male catkins in the first and second year of the experiment (see Table 3). A positive significant effect on the number of falling male catkins in the first year of the experiment (flowering of 1971) was caused by a medium level of nitrogen fertilisation (Fig. 4). However the nitrogen could not have affected the induction of male flowers, but it only regulated their fall.

The effect of mineral fertilisation in the second year of the experiment (1972) concerned the proces of floral initiation that took place in 1971, after the fertilizers were distributed. A significant effect on the

Table 3

Effect of mineral fertilisation on the spruce stand in Szczyrk. Significant results as determined by the variance analysis

Wpływ nawożenia mineralnego na drzewostan w Szczyrku. Istotne wyniki analiz wariancyjnych

Source of variance Źródło zmienności	Year of experiment Rok doświadczenia	Characters – Cechy						
		No. of male catkins Liczba kwiatów męskich	No. of seeds Liczba nasion	Wt. of 1000 seeds Waga 1000 nasion	Dry wt. of litter Sucha masa ściółki	% of litter falling in summer % ściółki opadającej latem	% Ca in secondary bark % Ca w korze wtórnej	% Na in secondary bark % Na w korze wtórnej
N	1	+			+			
	2			+	++			
	3				+++	+		
	4							
P	1		+					
	2							
	3							
	4							
K	1							
	2							
	3							
	4							
N×P	1		+		+			
	2	+						
	3							
	4							
N×K	1		++	+	+			
	2	+						
	3							
	4							
P×K	1		++					
	2	+						
	3						++	+
	4							
N×P×K	1		+					
	2							
	3							
	4							
Blocks Bloki	1							
	2							
	3						+	
	4							

+ significant at 0.05 level – istotne przy poziomie 0,05;
++ significant at 0.01 level – istotne przy poziomie 0,01
+++ significant at 0.001 level – istotne przy poziomie 0,001;

Table 4

Cones falling from the spruce stand canopy in Szczyrk

Opad szyszek w drzewostanie świerkowym w Szczyrku

Year of flowering Rok kwitnienia	Year of collection Rok zbioru	Mean no. of cones per m² Średnia liczba szyszek na 1 m²	Mean no. of cones per tree Średnia liczba szyszek na 1 drzewo
1970	4 VIII 1971 - 6 IV 1972	0.52	9.5
1971	6 IV 1972 - 9 V 1973	1.74	31.8
1972	9 V 1973 - 23 IV 1974	0.11	2.0
1973	23 IV 1974 - 7 V 1975	0.23	4.2

Table 5

The fall of male catkins from a spruce stand canopy in Szczyrk
Opad kwiatów męskich w drzewostanie świerkowym w Szczyrku

Year of flowering Rok kwitnienia	Year of collection Rok zbioru	Mean no. of male catkins per m² Średnia liczba kwiatów męskich na 1 m²	Mean no. of male catkins per tree Średnia liczba kwiatów męskich na 1 drzewo
1971	4 VIII 1971 - 6 IV 1972	26.4*	482.6*
1972	6 IV 1972 - 9 V 1973	1.6	29.2
1973	9 V 1973 - 23 IV 1974	9.3	170.0
1974	23 IV 1974 - 7 V 1975	1.0	18.3

* Incomplete collection year, without June and July.

number of flowers collected in the period from the spring of 1972 till the spring of 1973 has been exerted by fertilizers interacting in the following combinations: nitrogen and potassium, phosphorus and potassium, and also nitrogen and phosphorus. Nitrogen increased the number of catkins in the presence of potassium (Fig. 5). The potassium fertilizer was most effective in stimulating catkin numbers in the absence of phosphorus fertilisation (Fig. 6). Also nitrogen-phosphorus interaction had a significant influence. Compared with the control variant a significant increase in the number of flowers was caused by a balanced NP fertilisation

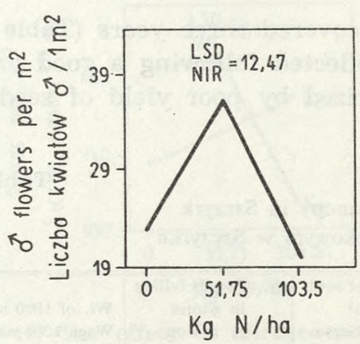

Fig. 4. The effect of nitrogen fertilisation on the number of male catkins in the first year of the experiment

Ryc. 4. Wpływ nawożenia azotowego na liczbę kwiatów męskich w pierwszym roku doświadczenia

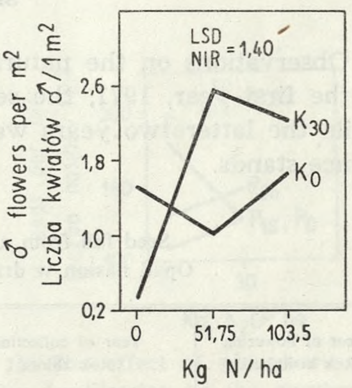

Fig. 5. The effect of nitrogen-potassium fertilisation on the number of male catkins in the second year of the experiment

Ryc. 5. Wpływ nawożenia azotem i potasem na liczbę kwiatów męskich w drugim roku doświadczenia

(mean or maximal doses of both fertilizers) or by nitrogen given without phosphorus (Fig. 7). In the latter case probably the positive though not significant overall effect of nitrogen on male strobile induction is being manifested (see Fig. 24).

Visual estimates of male flowering yielded no significant results.

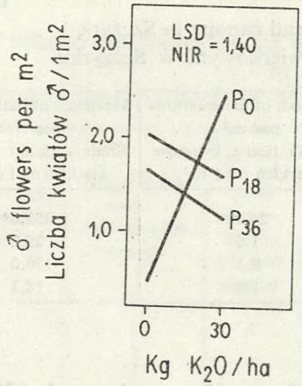

Fig. 6. The effect of phosphorus-potassium fertilisation on the number of male catkins in the second year of the experiment

Ryc. 6. Wpływ nawożenia fosforem i potasem na liczbę kwiatów męskich w drugim roku doświadczenia

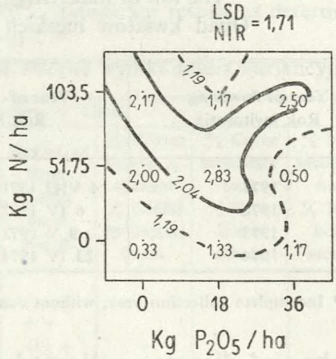

Fig. 7. The effect of nitrogen-phosphorus fertilisation on the number of male catkins in the second year of the experiment

Ryc. 7. Wpływ nawożenia azotem i fosforem na liczbę kwiatów męskich w drugim roku doświadczenia

SEED PRODUCTION

Observations on the natural seed fall covered three years (Table 6). In the first year, 1971, the seeds were collected following a good crop, while the latter two years were characterized by poor yield of seed in spruce stands.

Table 6

Seed fall from a spruce stand canopy in Szczyrk
Opad nasion w drzewostanie świerkowym w Szczyrku

Year of flowering Rok kwitnienia	Year of collection Rok zbioru	Mean no. of seeds per m² Średnia liczba nasion na 1 m²	% of seeds falling in winter % nasion opadających zimą	Wt. of 1000 seeds Waga 1000 nasion
1971	4 VIII 1971 - 28 X 1972	165.9	95.6	5.13
1972	28 X 1972 - 6 XI 1973	5.2	55.9	4.26
1973	6 XI 1973 - 19 XI 1974	5.0	51.3	4.31

It is noticeable that the seed fall is not uniform (the % of seeds falling in winter) in the individual years. Following a good seed crop almost all the seeds fall during the winter immediately after the flowering, while in the years of poor crops, during the same time only one half of the seeds falls, while the remaining seeds fall in the spring one year after flowering. The weight of 1000 seeds changed over the years of the experiment. The heaviest seeds were collected in the first year of the experiment after a good crop.

Mineral fertilisation has had an effect on the number of falling seeds in the first year and on the weight of 1000 seeds in the second year (Table 3). From Fig. 8 it can be seen that the phosphorus fertilisation used in the lowest dose has significantly decreased the number of seeds. This effect of phosphorus is also contained in the NxP interaction; the significant low negative effect of the medium phosphorus dose was observable only in the absence or low level of nitrogen fertilisation (Fig. 9). A decrease in the number of seeds occured also as a result of the action of the maximal dose of nitrogen in the absence of potassium fertilisation (N×K interaction) (Fig. 10). Analysing the P×K interaction it can be said that every fertilisation including both phosphorus and potassium has had a negative effect on the number of seeds compared with the unfertilised control (Fig. 11). The third order interaction is more difficult to

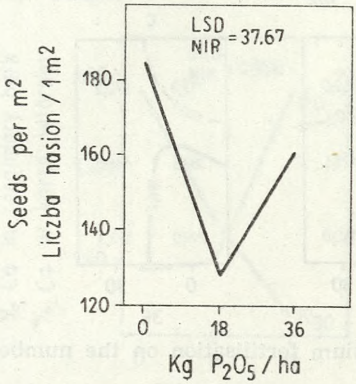

Fig. 8. The effect of phosphorus fertilisation on the number of seeds

Ryc. 8. Wpływ nawożenia fosforowego na liczbę nasion

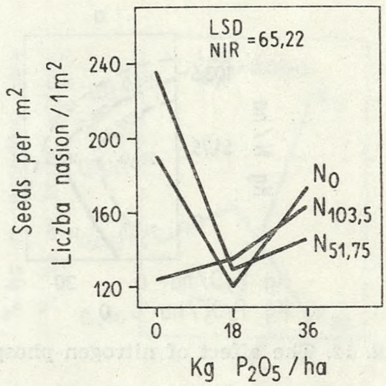

Fig. 9. The effect of nitrogen-phosphorus fertilisation on the number of seeds

Ryc. 9. Wpływ nawożenia azotem i fosforem na liczbę nasion

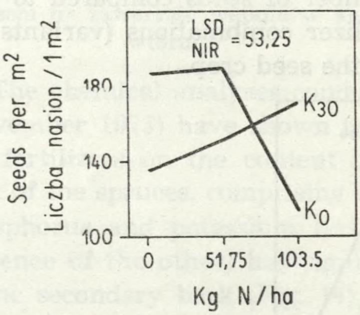

Fig. 10. The effect of nitrogen-potassium fertilisation on the number of seeds

Ryc. 10. Wpływ nawożenia azotem i potasem na liczbę nasion

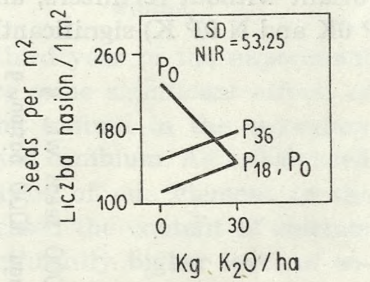

Fig. 11. The effect of phosphorus-potassium fertilisation on the number of seeds

Ryc. 11. Wpływ nawożenia fosforem i potasem na liczbę nasion interpret. Its significance is primarily caused by the negative effect of a medium level of phosphorus fertilisation (Fig. 12b) while in the absence of phosphorus or when its maximal dose was used nitrogen fertilisation has had negative effect on seed number provided potassium was not ap-

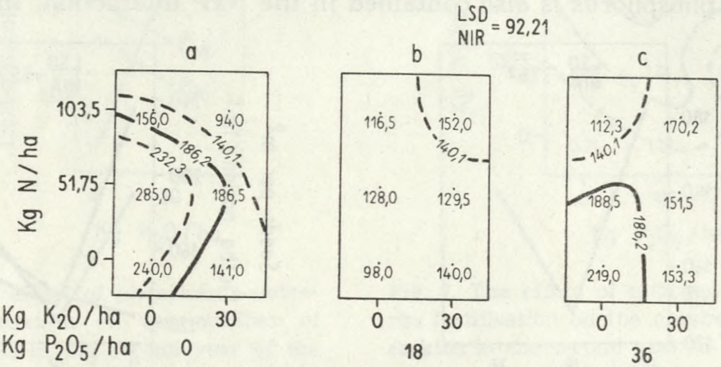

Fig. 12. The effect of nitrogen-phosphorus-potassium fertilisation on the number of seeds

Ryc. 12. Wpływ nawożenia azotem, fosforem i potasem na liczbę nasion

plied (Fig. 12a and c). This result includes the effect of joint nitrogen nad potassium fertilisation discussed above. Generaly it can be said that full fertilisation has not improved the number of seeds compared to the variant without fertilizers, and some fertilizer combinations (variants 0N P 0K and N 0P K) significantly decreased the seed crop.

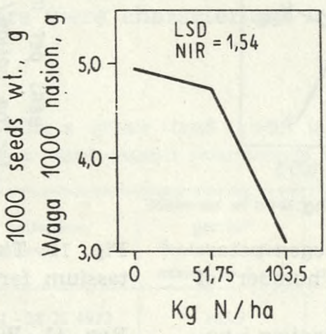

Fig. 13. The effect of nitrogen fertilisation on the weight of 1000 seeds in the second year of the experiment

Ryc. 13. Wpływ nawożenia azotem na wagę 1000 nasion w drugim roku doświadczenia

The 1000 seed weight (including both full and empty seeds) in the second year of experiment, when the seed crop was small, was significantly affected only by the nitrogen fertilisation. From Fig. 13 it can be seen that the maximal dose of nitrogen has caused a reduction in the weight of 1000 seeds by almost 2 grams (from 4.92 g to 3.09 g).

GROWTH INCREMENTS AND MINERAL CONCENTRATIONS IN TREES

Mineral fertilisation has not had any significant effect on the girth increments in individual years nor jointly for the 4 years of the experiment. There was also no effect on the late wood percentage in these growth rings.

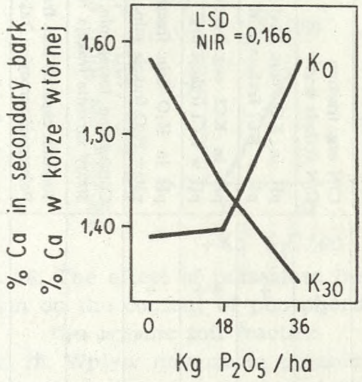

Fig. 14. The effect of phosphorus-potassium fertilisation on the calcium content in the secondary bark

Ryc. 14. Wpływ nawożenia fosforem i potasem na zawartość wapnia w korze wtórnej

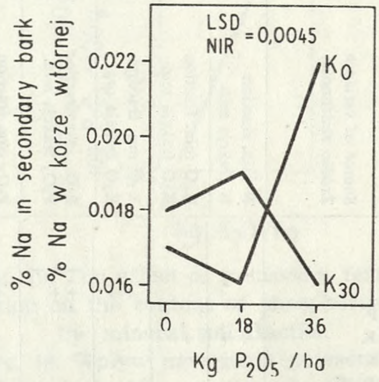

Fig. 15. The effect of phosphorus-potassium fertilisation on the content of sodium in the secondary bark

Ryc. 15. Wpływ nawożenia fosforem i potasem na zawartość sodu w korze wtórnej

The chemical analyses conducted in the third year of the experiment (November 1973) have shown that there were some significant effects of the fertilizers on the content of calcium and sodium in the secondary bark of the spruces, comprising both phloem and cambium. An unbalanced phosphorus and potassium fertilisation (absence of one element in the presence of the other) has significantly increased the content of calcium in the secondary bark (Fig. 14), while a significantly higher level of sodium occured when the treatment included maximal phosphorus but no potassium fertilisation (Fig. 15).

THE SOIL

Table 7 summarises the significant effects of mineral fertilisation on the forest soil in the studied stand. When interpreting the fertilizer effects on the trees only selected results from Table 7 are utilized. Generally the soil responses will be the subject of a separate paper (Dzięciołowski et al. 1977).

Fig. 16 presents the negative effect of nitrogen fertilisation together with potassium (N×K interaction) on the content of nitrogen in the mineral soil fraction. A similar though not significant result was obtained using nitrogen alone.

Table 7

Effects of mineral fertilisation on the soil. Significant results from variance analysis

Zmiany w glebie spowodowane nawożeniem mineralnym. Istotne wyniki analiz wariancyjnych

Source of variance Źródło zmienności	Characters – Cechy													
	N min. fraction N frakcja min.	K_2O min. fraction K_2O frakcja min.	K_2O org. fraction K_2O frakcja org.	P_2O_5 min. fraction P_2O_5 frakcja min.	P_2O_5 org. fraction P_2O_5 frakcja org.	C org. fraction C frakcja org.	C/N min. fraction C/N frakcja min.	C/N org. fraction C/N frakcja org.	pH in KCl min. fraction pH w KCl frakcja min.	pH in KCl org. fraction pH w KCl frakcja org.	pH in H_2O min. fraction pH w H_2O frakcja min.	Combustion losses min. fraction Straty żarzenia frakcja min.	Sorption capacity min. fraction Pojemność sorpcyjna frakcja min.	Mg min. fraction Mg frakcja min.
N		++				++		+		+				
P				+++			+							
K			++	++	++				+	++	+			
N×P								+						
N×K	++	+										++		
P×K													+	
N×P×K					+									+
Blocks Bloki														

+ significant at 0.05 level – istotne przy poziomie 0,05;
++ significant at 0.01 level – istotne przy poziomie 0,01;
+++ significant at 0.001 level – istotne przy poziomie 0,001.

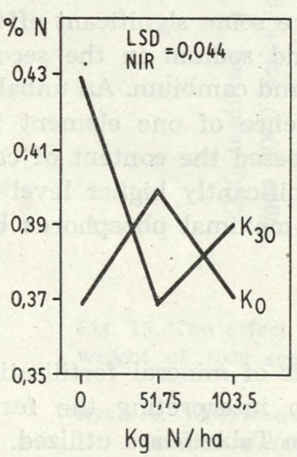

Fig. 16. The effect of nitrogen-potassium fertilisation on the nitrogen content in the mineral soil fraction

Ryc. 16. Wpływ nawożenia azotem i potasem na zawartość azotu w mineralnej frakcji gleby

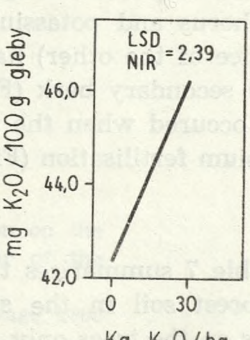

Fig. 17. The effect of potassium fertilisation on the content of potassium in the organic soil fraction

Ryc. 17. Wpływ nawożenia potasem na zawartość potasu w organicznej frakcji gleby

Potassium fertilisation increased significantly the level of potassium in the organic soil fraction (Fig. 17) and nonsignificantly in the mineral fraction. Under the influence of the same potassium fertilisation also

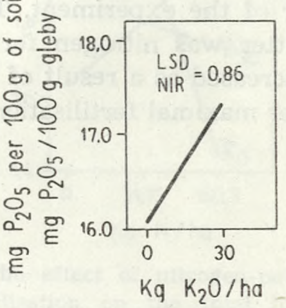

Fig. 18. The effect of potassium fertilisation on the content of phosphorus in the organic soil fraction

Ryc. 18. Wpływ nawożenia potasem na zawartość fosforu w organicznej frakcji gleby

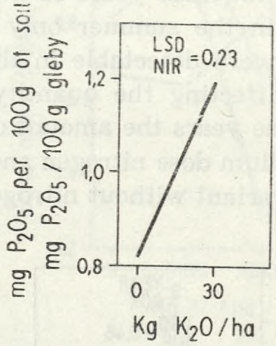

Fig. 19. The effect of potassium fertilisation on the content of phosphorus in the mineral soil fraction

Ryc. 19. Wpływ nawożenia potasem na zawartość fosforu w mineralnej frakcji gleby

a significant increase of phosphorus level was observed in both the organic and mineral fractions (Figs. 18 and 19).

In general the mineral fertilisation has altered 14 out of the 21 soil parameters measured.

LITTER FALL

The amount of litter falling during the four consecutive years of the experiment, expressed as dry weight varied considerably (Table 8).

Table 8

Litter fall from a spruce stand canopy in Szczyrk
Opad ściółki w drzewostanie świerkowym w Szczyrku

Year of flowering Rok kwitnienia	Year of collection Rok zbioru	Mean litter fall in tons per ha Średnia ilość ściółki ton/ha	% of litter falling in the summer % ściółki opadającej latem
1971	4 VIII 1971 - 6 IV 1972	1.76	–
1972	6 IV 1972 - 9 V 1973	2.82	36.2
1973	9 V 1973 - 23 IV 1974	4.35	34.6
1974	23 IV 1974 - 7 V 1975	2.83	52.5

The mean annual fall of litter was 2.94 tons of dry weight per hectar. The smallest quantity of litter was collected in the year of good cone crop (1971). The amount of litter falling during the vegetative season (from May to October) varied from one third to one half of the annual total, thus the bulk of the litter falls in the winter.

Mineral fertilisation has had a significant effect on the litter fall in the first three years of the experiment and on the percentage of litter falling in the summer only in the third year (Table 3). No significant effects were detectable in the fourth year of the experiment. The basic factor affecting the quantity of falling litter was nitrogen fertilisation. In all the years the amount of the litter increased as a result of applying the medium dose nitrogen and declined after maximal fertilisation relative to the variant without nitrogen (Fig. 20).

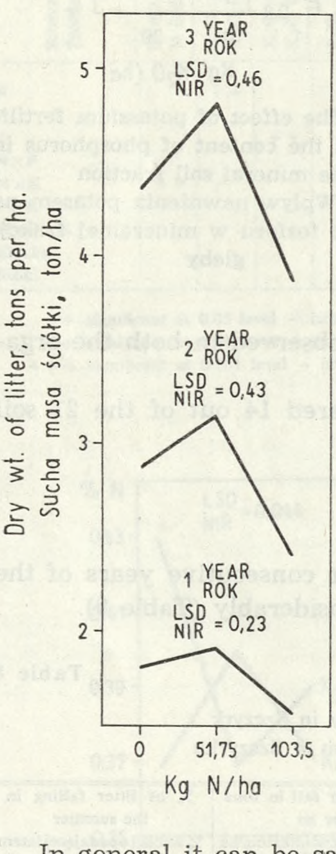

Fig. 20. The effect of nitrogen fertilisation on the total weight of litter falling from the canopy
Ryc. 20. Wpływ nawożenia azotem na opad ściółki

In general it can be said that nitrogen reduced the fall of litter. The negative effect of nitrogen affects also the interactions N×K (Fig. 21) and N×P (Fig. 22). In the first case nitrogen reduced the amount of litter in the absence of potassium while in the latter the negative effect of nitrogen was observed in the absence of phosphorus and in the presence of its maximal dose.

Nitrogen fertilisation has also decreased significantly the percentage of litter falling in the summer during the third year (Fig. 23).

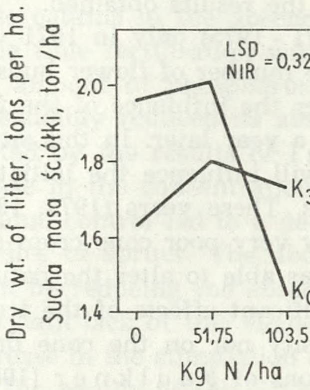

Fig. 21. The effect of nitrogen-potassium fertilisation on the total litter drop in the first year of the experiment

Ryc. 21. Wpływ nawożenia azotem i potasem na opad ściółki w pierwszym roku doświadczenia

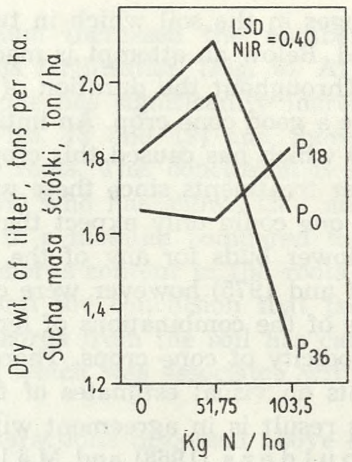

Fig. 22. The effect of nitrogen-phosphorus fertilisation on the total litter drop in the first year of the experiment

Ryc. 22. Wpływ nawożenia azotem i fosforem na opad ściółki w pierwszym roku doświadczenia

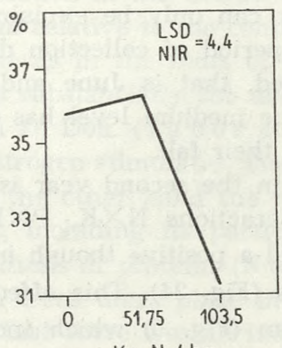

Fig. 23. The effect of nitrogen fertilisation on the percentage of litter droping from the canopy during the vegetative season in the third year of the experiment

Ryc. 23. Wpływ nawożenia azotem na procent ściółki opadającej w ciągu sezonu wegetacyjnego w trzecim roku doświadczenia

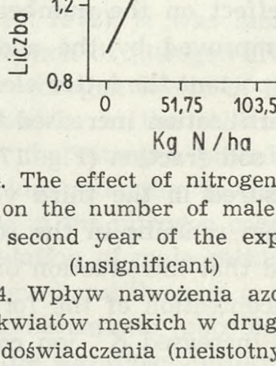

Fig. 24. The effect of nitrogen fertilisation on the number of male catkins in the second year of the experiment (insignificant)

Ryc. 24. Wpływ nawożenia azotem na liczbę kwiatów męskich w drugim roku doświadczenia (nieistotny)

DISCUSSION

As was indicated in the introduction the soil was considered in this experiment as a constant and even factor. The introduction into it of various fertilizer combinations as the experimental treatments has caused changes in the soil which in turn affected the characters of the studied stand. Below an attempt is made to interpret the results obtained.

Throughout the duration of the study (1971 - 1975) only in 1971 was there a good cone crop. An initiation of a large number of flower buds in 1970 which has caused this crop was not under the influence of the fertilizer treatments since these were performed a year later. In this situation one could only expect that fertilisation will influence the initiation of flower buds for any of the following years. These years (1972, 1973, 1974 and 1975) however were characterized by very poor cone crops and none of the combinations of fertilizers used was able to alter the natural periodicity of cone crops. There were no significant effects of the treatments on visual estimates of flowering intensity nor on the cone drop. This result is in agreement with the conclusions of Faulkner (1966), Shoulders (1968) and Mälkönen (1971) who believe that mineral fertilisation may increase the production of cones only when it precedes appropriate weather conditions favourable to the induction of female flowers.

The next character analysed was the number of falling male catkins. Mineral fertilisation has had an effect on this character only in the first and the second year of the experiment. A positive effect of nitrogen on the number of male catkins in the first year can only be explained by changes in the rate of their abscission. The period of collection did not cover the time immediately after pollen shed, that is June and July. It appears therefore that nitrogen given at the medium level has extended the viability of male catkins and retarded their fall.

An interpretation of the results obtained in the second year is made difficult by the significant second order interactions N×K, P×K and N×P. Fertilisation with nitrogen only has had a positive though insignificant effect on the number of male flowers (Fig. 24). This effect was much improved by the addition of potassium (Fig. 5) which indicates how important the latter element is. Soil analyses have shown that potassium fertilisation increased the amount of potassium significantly in the organic soil fraction (Fig. 17) and insignificantly in the mineral fraction, as measured in the third year after the treatment. This indicates that potassium remains in the soil for a long time. On this basis it can be assumed that introduction of potassium together with nitrogen increased the concentration of the former in the soil. It is known (Koter 1972), that an increased K^+ ion concentration in a solution stimulates the absorption of NO_3^- ions by the roots. Thus it can be concluded that an increase in the number of male flowers was the direct result of an increase in the concentration of nitrogen in the tree caused by an increased absorption due to the presence of additional potassium.

A significant medium effect of potassium was manifest also in the phosphorus-potassium interaction. Potassium increased the number of male catkins in the absence of phosphorus fertilisation (Fig. 6). At the same time fertilisation with potassium alone has significantly increased the amount of phosphorus in the soil (Figs. 18 and 19) and therefore presumably reduced its absorption by the roots. This conclusion is supported by the results of Ingestad (1959) who has shown that an increase in the concentration of potassium in a medium compared to the optimal control led to a decrease of phosphorus content in the roots and needles of spruce. The above results permit the conclusion that potassium by reducing the absorption of phosphorus from the soil has caused a certain lack of this element in the trees which was associated with an increase in the stimulation of male catkins.

The results of the N×K and P×K interactions discussed above suggest a positive effect of nitrogen and a negative one of phosphorus on the initiation of male catkins in the presence of significantly greater levels in the soil. When phosphorus is given together with nitrogen its effect changes, it starts influencing positively the male catkin production. This is manifest in the positive effect of a balanced nitrogen and phosphorus fertilisation (Fig. 7). The interaction of nitrogen and phosphorus finds confirmation in the literature. An increase in the level of nitrogen in a medium relative to the control causes an increase in the concentration of phosphorus in the roots of spruce seedlings (Ingestad 1959) and increases substancially the absorption of phosphorus by seedlings of *Pinus radiata* D. Don. (Taber and McFee 1972). Thus it can be concluded that nitrogen stimulates phosphorus absorption.

On the other hand the role of phosphorus in nitrogen metabolism is known, including its participation in the reduction of nitrates in the biosynthesis of proteins (Nowotny-Mieczyńska 1965), which process in trees takes place in the roots (Koter 1972). It was mentioned above that there was an increase in the absorption of nitrogen from the soil which is indicated by lack of changes in nitrogen levels in the soil following fertilisation with this element (Table 7). In the circumstance the introduction of phosphorus together with the nitrogen probably led to an intensification of the process of nitrate ions reduction in the roots, and consequently could have led to an increase in the nitrogen concentration in the trees and an increase in the stimulation of male catkins.

The results obtained indicate that on the one hand there is a diversified effect of the same element in various combinations (phosphorus in PK and in NP), and on the other point to the significant effect of nitrogen on the production of male catkins in a year of poor crop. A similar positive effect of nitrogen on the production of male catkins has been reported for Douglas fir (Jackson and Sweet 1972).

The negative effect of various fertilizer combinations on the quantity of seeds in the first year of the experiment also requires some biological explanation. The mineral fertilisation could not have affected the induction of female cones since that process took place one year before the fertilizer treatment. One must also exclude the possible negative role of fertilizers on the proces of pollination and fertilisation, since the fertilizers were applied already after pollination and unfertilised archegonia develop in spruce into empty seeds (Sarvas 1968), thus lack of fertilisation would have not affected the total number of both full and empty seeds. In the circumstance the effect of the mineral fertilisation on the number of seeds could have been effected through the intensification of natural abortion of pollinated but not fully developed cones.

One should also note that there was a negative effect of nitrogen on the weight of 1000 seeds in the second year of experiment. A similar result was obtained by Heinze and Wagner (1973). The weight of 1000 seeds is determined primarily by the percentage of empty seeds.

According to Sarvas (1968) this percentage increases rapidly in the years of poor crop, primarily due to lack of sufficient pollen. Probably also in the analysed seed collection there was a high percentage of empty seeds, which was increased by the addition of nitrogen fertilizer at the highest level. On the other hand nitrogen fertilisation increased the number of male catkins in the same year (Fig. 5 and 24). This fact would indicate that an increase in percentage of empty seeds and at the same time a reduction of the weight of 1000 seeds was not in this case a result of lower availability of pollen. However empty seeds develop in spruce not only as a result of pollen insufficiency, but also due to abortion of already formed embryos (Sarvas 1968). It is highly likely therefore that nitrogen fertilisation, through an increase in the concentration of nitrogen in the trees, caused aberrations in the fertilisation process or stimulated the abortion of embryos, and in effect reducing the weight of 1000 seeds.

Another cause of the reduction in 1000 seed weight coupled with increased pollen availability could have been a fertilizer induced change in the time of male and female flowering and therby reduced the number that flowered simultaneously.

Absence of any effect of the fertilizers on girth increment or on the percentage of the late wood in the growth rings during four years after the fertilisation, indirectly confirms the initial assumption that an optimal very rich site would provide the stand with optimal growth conditions. Introduction of additional mineral nutrients was from the point of view of growth useless. None the less the trees have responded to the treatments which is indicated by the analyses of the secondary bark. The increased content of calcium in the secondary bark was probably the result of an increased calcium absorption from the soil. The higher level of sodium in the absence of potassium fertilisation may be due a higher absorption of Na from the soil in such conditions, which conclusion finds confirmation in the literature (Nowotny-Mieczyńska 1965). It is also known that plants absorb sodium more intensively when it is in the phosphate form that in the form of a chloride (Nowotny-Mieczyńska 1965) which to some extent explains the significant effect of phosphorus fertilisation on the concentration of sodium in the secondary bark.

A comment might be made here in connection with the increasingly common practice of fertilising forests from air-planes. The result obtained here indicates that this fertilisation may be quite ineffective in increasing tree growth on a rich site. Thus use of this method of fertilising over wide forest areas without considering the diversity of site conditions is to a large extent an economically unjustified procedure.

The last of the characters considered in the stand was the fall of litter from the canopy. Depending on the geographic location and the age spruce stands drop various quantities of litter. The bulk of the weight lies in the needles — about 70% (Bonnevie-Svendsen and Gjems 1957). Compared with the average drop in Szczyrk which amounted to 2.94 tons per ha per annum it can be mentioned that in lowland Norway the corresponding value was 1.9 - 3.3 tons (Mork 1942).

The amount of litter differs substancially from year to year. In the studied stand there was a very low drop in 1971, about 60% of the average over many years. This drop might have been caused by the good cone crop which occured in that year. Morris (1951) reports that in a good cone crop year in *Abies balsamea* (L.) Mill. there occurs a drop in the weight of new foliage forming on a tree down to about 73%. Also in Douglas fir a considerable reduction in the length of needles and shoots is assiociated with abundant cone production (Tappeiner 1969).

The litter drop in a stand is associated with many ecological factors, including the richness of the soil in mineral components (Addicott and Lyon 1973). In the studied stand the analyses have shown a significant, persistent over three years, negative effect of nitrogen fertilisation on the litter drop. This effect can be explained through a physiological consideration of the mechanisms regulating the leaf drop.

It is known that the main inhibitor of leaf abscission is auxin, IAA, the concentration of which in the leaves is positively correlated with the availability of nitrogen in the soil. Thus a lowering in the auxin concentraction caused by nitrogen depletion in the soil causes an increase in the leaf fall (Addicott and Lyon 1973). In the case of our experiment the opposite reaction was observed — the soil was enriched in nitrogen. Thus conditions were created for a more intensive IAA synthesis (or of other growth regulators) and in consequence an increase in its concentration which prolonged the persistence of needles on the shoots and reduced their abscission. This phenomenon occured primarily during the growing season which is indicated by a reduction in the amount of litter falling in the spring and summer as a result of nitrogen fertilisation.

To summarise it has to be stated that mineral fertilisation of a spruce stand growing on a rich site has not produced any marked effects. It has not affected the number of female flowers induced during a poor seed year and it has not affected the periodicity of cone crops. Only some positive effects were obtained on the induction of male catkins. The above conclusions can be of practical value in the planned and in places already performed mineral fertilisation of seed stands. It appears that primarily in the case of seed stands, which as a rule grow on the best sites for the given species, mineral fertilisation will be an ineffective and economically unjustifiable procedure.

SUMMARY

The effect of mineral fertilizer application on the flowering and seed crops in Norway spruce has been studied through an analysis of the annual litter drop. The studies were conducted in an 82-year old stand growing on a rich mountain site in compt. 155c of Forest District Szczyrk. In spring 1971 N, P and K fertilizers were distributed in 18 different combinations of doses on 0.1 ha plots in three replicate blocks. The observations made led to the following conclusions.

1. Mineral fertilisation of the stand did not affect significantly the female flowering in the stand in poor crop years nor did it alter the natural periodicity of seed crops.

2. A significant effect on the production of male catkins has been exerted by nitrogen-potassium, phosphorus-potassium and nitrogen-phosphorus fertilizer combinations. The results suggest that nitrogen has generally a positive effect on male catkin induction and phosphorus a negative one.

3. Some fertilizer combinations have significantly lowered the number of seeds falling from the canopy following a good cone crop year. Nitrogen fertilisation significantly decreased the weight of 1000 seeds in a poor seed crop year.

4. A spruce stand growing on a rich soil did not respond with improved growth to any of the fertilizer combinations applied. The chemical composition of the secondary bark (phloem and cambium) on these trees was altered.

5. Chemical analyses of the soil indicated that three years after the fertilizer treatments there were still many significant changes observable in soil.

6. Nitrogen fertilisation reduced the total litter fall in the stand and the proportion of the litter falling during the vegetative season.

7. In the light of the results obtained, fertilisation of spruce stands from air without taking into consideration the diversity of sites is to a

large extent an economically unjustifiable proposition. Also mineral fertilisation in seed stands, aimed at improving the seed yield, will most likely be ineffective and a wasted investment.

I wish to thank laboratory assistants Zofia Kozłowska, Alicja Piekuta, Janina Góźdź, Zbigniew Królikowski and Mariola Andrejew for the laborious sorting of the litter.

Institute of Dendrology
Kórnik nr. Poznań

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WŁADYSŁAW CHAŁUPKA

Badanie wpływu nawożenia mineralnego na obradzanie szyszek i nasion świerka pospolitego (Picea abies (L.)Karst.) przez analizę opadu ściółki w drzewostanie

Streszczenie

Wpływ nawożenia mineralnego na kwitnienie i obradzanie nasion u świerka pospolitego badano poprzez analizę opadu ściółki w cyklach rocznych. Obiektem doświadczenia był 82-letni drzewostan, rosnący na żyznym siedlisku lasu górskiego w oddziale 155c Nadleśnictwa Szczyrk. Wiosną 1971 r. rozsiano nawozy N, P i K w 18 różnych kombinacjach na 10-arowych poletkach w trzech powtórzeniach. Przeprowadzone analizy doprowadziły do następujących wyników:

1. Nawożenie mineralne drzewostanu nie wywarło istotnego wpływu na obfitość kwitnienia żeńskiego w latach słabego urodzaju i nie zmieniło naturalnej okresowości obradzania nasion.

2. Istotny wpływ na ilość kwiatów męskich wywarło nawożenie azotowo-potasowe, fosforowo-potasowe i azotowo-fosforowe. Wyniki sugerują pozytywną rolę azotu i negatywną fosforu w procesie zawiązywania kwiatów męskich.

3. Niektóre kombinacje nawozów zmniejszyły istotnie ilość nasion opadających po roku dobrego urodzaju. Nawożenie azotowe zmniejszyło istotnie wagę 1000 nasion w roku słabego urodzaju.

4. Drzewostan świerkowy rosnący na żyznej glebie nie zareagował wzmożeniem

przyrostu grubości na zastosowane kombinacje nawozów. Zmienił się natomiast skład chemiczny kory wtórnej (łyka i miazgi).

5. Analizy chemiczne gleby wykazały zmiany licznych jej cech pod wpływem różnych wariantów nawożenia, wykonanego trzy lata wcześniej.

6. Nawożenie azotowe zmniejszyło opad ściółki w drzewostanie oraz procent ściółki opadającej w sezonie wegetacyjnym.

7. W doświadczeniu nie wykazano wpływu żadnej z osiemnastu kombinacji nawożenia mineralnego na przyrost grubości drzew. Wynik ten wskazuje na fakt, iż nawożenie lasów z samolotów, stosowane bez uwzględniania zróżnicowania siedlisk, jest inwestycją w znacznym stopniu nie uzasadnioną ekonomicznie. Również nawożenie mineralne drzewostanów nasiennych, podejmowane z myślą o zwiększeniu produkcji nasion, będzie najprawdopodobniej mało skuteczne i nieopłacalne.

ВЛАДЫСЛАВ ХАЛУПКА

Изучение влияния минеральных удобрений на цветение и плодоношение ели обыкновенной (Picea abies (L.) Karst.)

Резюме

Влияние минеральных удобрений на цветение и плодоношение ели обыкновенной изучалось с использованием анализа опада. В качестве объекта был выбран участок елового древостоя в горном лесничестве Щирк (западные Карпаты). Возраст древостоя — 82 года, средняя высота деревьев — 26 м, средний диаметр — 33 см, местоположение — крутое, почва — буроземная кислая.

Весной 1971 года были внесены минеральные удобрения (N, P и K) — восемнадцать комбинаций в трёх повторениях. Величина каждого опытного участка — 10 аров, общая площадь опытного древостоя — 5,4 гектара. Результаты полученные в этом опыте привели к следующим выводам.

1. Внесение минеральных удобрений не оказало существенного влияния на количество женских цветков в малоурожайные годы и не изменило естественной периодичности плодоношения.

2. Значительное влияние на количество мужских цветков оказали удобрения NK, PK и NP. Результаты опытов говорят о положительной роли азота и отрицательной роли фосфора в процессе образования мужских цветков.

3. Некоторые комбинации удобрений вызывали существенное уменьшение количества семян опадающих после года хорошего урожая. Азотное удобрение значительно уменьшило вес 1000 семян в год слабого урожая.

4. Примененные комбинации минеральных удобрений не вызвали увеличения прироста деревьев по диаметру в еловом древостое, растущем на плодородной почве. В то же время изменился химический состав вторичной коры.

5. Химические анализы почвы выявили изменения многих ее свойств под влиянием различных вариантов удобрений, примененных за три года до производства анализов.

6. Азотное удобрение уменьшило размеры опада и процент той его части, которая опадает во время вегетационного периода.

7. В свете полученных результатов удобрение лесов с самолетов без учета дифференциации местообитаний представляется инвестицией в значительной степени экономически необоснованной. Также и применение минеральных удобрений семенных древостоев, предпринимаемое с целью увеличения плодоношения, вероятнее всего, будет мало эффективным и нерентабельным.