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Relation between climatic factors and Scots pine (*Pinus silvestris* L.) cone crops in Poland*

INTRODUCTION

Flowering and seed crops in Scots pine depend on several internal and external factors. According to Giertych (1967) internal factors such as genetic determinants, degree of plant maturation and the general state of variability of the individual constitute prerequisits for the flowering process, which is later modified, stimulated or inhibited by external factors among which certain climatic parameters such as temperature, precipitation and insolation might be of primary importance. Since pine cones develop over two and a half years it is necessary to consider the climatic conditions throughout that period as well as in the year before flower initiation. At the time flower buds are being initiated and their initial development takes place weather conditions appear to be of the greatest significance for the future cone crop. Thus it is in that period that most students of the problem have been looking for relations between climatic parameters and cone crops.

Hagen (1917, see Andersson 1965) has shown that high summer temperatures are necessary for the initiation and development of flower buds in *Pinus silvestris*. The same was observed by Daubenmire (1960) for *Pinus resinosa* Laws. La Bastide and Van Vredenburch (1970) have shown a distinctly positive effect of light and temperature during the summer and early autumn two years before seed ripening in *Pinus silvestris*. Cajander (1917, see Sarvas 1962) reports that the formation of female flowers in *Pinus silvestris* is greatest on trees growing in full light, while male flowers are frequently formed on trees growing in considerable shade. It is known for many woody plants including pines that shading reduces the initiation of flower buds (Jackson and Sweet 1972).

Air humidity also has an effect on the seed crop in Pinus silvestris,

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particularily in the period preceding the initiation of flower buds (G i r g i d o v 1960, C h i r ŏ v 1964).

Precipitation is another important factor regulating the initiation of flower buds. This of course is closely associated with the air humidity and with the availability of water for the plant. The seed crop in *Pinus taeda* depends on an adequate precipitation during the differentiation of flower initials, that is about two years before seed maturation (W e n g e r 1957, L a m b et al. 1973).

MATERIALS AND METHODS

In table 1 the crop of mature pine cones in the years 1951 - 1965 is shown as averaged for four regions. For these regions representative meteorological stations were selected, namely Suwałki, Wałcz, Kórnik and Kudowa. The flowering estimate was made visually by the Forest Administration and reported annually to the Forest Research Institute in Warsow, where in the laboratory of seed studies the data was averaged for regions and summarised *. The data is given as the estimated percentage of a maximal crop. The average of such figures is of necessity much below 100% even in the years of highest crops.

Table 1

Scots pine cone crops in 4 regions expressed as percentage of the maximum for any region (Data supplied by the Forest Research Institute)

Year	Regions			
	I	II	III	IV
1951	24	20	27	27
1952	27	22	27	25
1953	26	25	20	18
1954	29	26	21	22
1955	38	28	61	46
1956	23	24	16	18
1957	22	22	19	18
1958	22	20	27	24
1959	19	22	21	17
1960	23	16	24	21
1961	23	19	20	19
1962	33	30	23	24
1963	18	17	14	14
1964	22	23	17	23
1965	24	30	24	18

Correlation coefficients *r* were calculated between the crop data and the climatic parameters over 48 months prior to the fall of mature seeds. Also the coefficients were calculated for the average figures for the whole year. The values were obtained separately for each of the four regions.

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Table 2

Correlations between climatic factors in various months of 4 years preceding seed maturation with the final cone crop as reported in Table 1. The correlation coefficents r were averaged over four regions through z transformation and expressed as positive or negative significant effects

Year relative to crop year	Month	Air temperature	Precipitation	Air moisture deficit	Insolation	Atmospheric pressure
Y-3	I					
	II				−	
	III		−−			
	IV	+++		++	++	
	V					
	VI				+	
	VII	++	−−−	+++	+++	+++
	VIII	+++		+++		
	IX	−−−		−−	−−	
	X	−−−				
	XI		++			
	XII	−−−	−−	−−		+++
Y-2	I		++	−−		
	II					
	III		−−−		+++	
	IV		−	++	++	+
	V	+		++	+	
	VI	+				
	VII	++		++	++	
	VIII					
	IX					
	X					
	XI			++	++	−
	XII		−−−			
Y-1	I	−				
	II		−−−		+	
	III	++				
	IV					
	V					
	VI	+++				
	VII	−−	+++	−−	−−	
	VIII		−−			
	IX	+++		+		
	X					
	XI				+	
	XII	++	++		−	
Y	I					−
	II					
	III	−		−−		
	IV				−−	
	V	−−−		−−		
	VI	−−−	−	−−		
	VII			−−		
	VIII					
	IX				−	
	X					
	XI	−				
	XII		++			
Y-3			−	+		+
Y-2				+++	+	
Y-1						
Y		−		−−−		

\+ significant at 0.1 level, ++ significant at 0.05 level, +++ significant at 0.01 level.

The climatic parameters considered were: 1° air temperature, 2° precipitation, 3° moisture deficit, 4° hours of insolation and 5° atmospheric pressure.

The correlation coefficients r were converted to Fisher z values which were then averaged over the four regions and converted back to r values. In this way averaged r values were obtained for the whole country. The significant results are indicated in Table 2.

RESULTS AND DISCUSSION

The climatic conditions have a significant effect on seed crops starting from the spring of the year preceding flower initiation to the summer of the year of seed maturation (Table 2). This influence is of course very uneven and only in a few short periods it is manifested through a strong correlation of the weather conditions with the generative response of pine trees.

Generally the greatest effect of weather on the seed crop was found in the year preceding initiation of flower buds. In April of that year a positive effect of a warm sunny weather was observed, and the same type of weather is necessary in July and August. On the other hand in the following autumn and winter a cool weather (low temperatures in September, October and December) favours the future crop.

Such a strong influence of meteorological factors on the seed crops, exerted already 40 months before their maturation, that is in the year preceding the year of flower initiation, has not been reported in the literature before and appears to be a very characteristic feature of the data discussed here. One cannot of course speak of the influence of weather on the flowering process itself since it has not started yet, but it is an indirect effect through other physiological processes such as nutrition, respiration, photosynthesis etc. As a result of these responses conditions are created in the tree, presumably through accumulation of storage substances, that will determine the intensity of floral induction in the following season.

In the following year, immediately before the initiation of flowers, a positive influence on the generative development is exerted by a sunny spring (March) with little precipitation. At the time of flower initiation, in July, a warm sunny weather favours the process.

Pollination takes place the following year in May (G i e r t y c h 1967). It is interesting that weather at that time is of no significance to the final seed crop. This is in agreement with the observation of S a r v a s (1962) who claims that the trees will not pollinate until a dry windy sunny day comes, and that happens eventually each year, and then the bulk of the pollen is shed within a few hours accomplishing full pollination. Thus even a generally wet spring will not be a hindrance to a full pollination.

Immediately after pollination, a positive influence on the final crop is exerted by high temperatures in June and then during the meiotic division of the macrospore mother cell in July a low temperature, overcast sky and high precipitation are favourable.

In Scots pine fertilisation takes place a year after pollination. Both before the fertilisation in May and after it in June low temperatures favoured the future seed crop.

All the climatic factors considered here, except for atmospheric pressure, appear to have a similar effect on the flowering processes, relative to the correlations between the factors. Temperature, insolation and moisture deficit have a common effect and precipitation an opposite one. It is not possible to say which of these factors is more important. This could only be shown by detailed studies under controlled conditions. Presumably the different factors reported by different authors as significantly influencing flowering such as air humidity (Girgidov 1960), insolation (La Bastide and Van Vredenburch 1970), light and temperature (Sarvas 1962) are in fact different expressions of one and the same weather condition.

One should remember that the units in which we express weather conditions are only of relative significance to the plants. According to Matthews (1963) the initiation of flower buds requires a certain minimal heat sum, higher than is necessary for the initiation of vegetative buds. One can assume that similarily as with other physiological processes there are certain optimal weather conditions for each phase of the generative development. Depending on the climatic conditions prevelant in any region these specific optimal requirements will be different for pines of different ecotype. For example when comparing a moist and a dry climate the pine growing there will have respectively a lower and a higher air moisture requirement relative to the average for the region (Chirov 1964).

As cans be seen from table 2 in the year of floral initiation and in the year proceding it, high temperatures in July favour the future seed crop. On the other hand immediately after pollination, in July of that year, a low temperature favours the future crop. Since in Scots pine the process of generative development is a long lasting one, taking several years each year there are generative organs in various stages of development. The optimal conditions for the whole process will occur rarely and this appears to be the reason why the occurrence of a good seed crop comes so irregularily. This has been suggested by Chałupka (1975) as the explanation for the rare seed years in Norway spruce in his studies on the relation between climatic factors and seed crops in that species.

It is perhaps relevant to point out here that relative to Norway spruce from the study of Chałupka (1975) the correlation coefficients with the climatic factors for pine are generally lower (Table 3). This would

Table 3

Correlation coefficients *r* between meteorological factors in the year of flower bud initiation and the future cone crop in Scots pine and Norway spruce. The data for spruce are from Chałupka (1975)

Months	Air temperature		Precipitation		Moisture deficit		Insolation	
	spruce	pine	spruce	pine	spruce	pine	spruce	pine
I	0.03	−0.03	0.27*	0.31**	−0.40***	−0.28**	−0.15	−0.17
II	0.23	−0.13	−0.10	−0.08	0.17	0.06	−0.09	0.02
III	0.39***	−0.11	−0.07	−0.37***	0.57****	0.16	0.41***	0.41***
IV	0.12	0.18	−0.14	−0.24*	0.29**	0.30**	0.44***	0.33**
V	−0.06	0.25*	−0.32**	−0.18	0.24*	0.30**	0.26*	0.26*
VI	0.49****	0.24*	−0.17	0.07	0.49****	0.12	0.49****	0.09
VII	0.45****	0.27**	0.25*	−0.10	0.23	0.30**	0.13	0.31**
VIII	−0.14	−0.08	−0.28**	0.11	0.02	0.12	0.34**	0.20
IX	−0.06	−0.01	0.02	−0.12	−0.01	0.14	0.04	0.15
X	0.23	0.06	−0.40***	0.03	0.35**	0.09	0.25*	−0.11
XI	0.09	−0.01	−0.31**	−0.17	0.49****	0.28**	0.49****	0.30**
XII	0.07	0.17	−0.26*	−0.35***	0.00	0.05	0.13	0.11

* significant at 0.1 level, ** at 0.05 level, *** at 0.01 level and **** at 0.001 level.

seem to suggest that the reproductive processes in pine have a greater tolerance to climatic conditions than in spruce. This may be the reason why pine produces cone crops more regularily than spruce.

SUMMARY

Correlations were sought between the seed crops in Scots pine (*Pinus silvestris* L.) over the years 1951 and 1965 and some meteorological factors occurring in 42 individual months preceding the maturation of the seeds. Statistical analyses of the data averaged over four climatic regions have indicated that the correlations between weather and future seed crops are strongest during the following stages of generative development: 1° one year prior to floral initiation, 2° during floral initiation, 3° immediately after pollination and 4° during fertilisation. In the year preceding floral initiation a warm sunny summer and a cool autumn favour seed crops. The strongest correlations with the seed crop were during that period and thus the weather at that time appears to be the primary determinant of future crops. The initiation of flowers is most abundant when during that year there is a sunny dry spring (March and April) and a warm sunny summer (July). In the following years, during flower and cone development generally low temperatures favoured the generative processes. The results suggest that for flowers in various stages of their long development different weather conditions are optimal and such patterns occur rarely. This appears to be the reason why good cone crops appear only in some years.

Compared to Norway spruce however pine has a greater tolerance to weather conditions indicated by lower correlation coefficients between fecundity and climatic parameters. This explains why cone crops are more common in pine than in spruce.

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Zależność między zjawiskami meteorologicznymi a urodzajem szyszek sosny zwyczajnej (Pinus silvestris L.) w Polsce

Streszczenie

Urodzaj nasion sosny (*Pinus silvestris* L.) w latach 1951 - 1965 skorelowano z niektórymi zjawiskami meteorologicznymi w ciągu 42 miesięcy poprzedzających dojrzewanie nasion. Analizy statystyczne wykazały istotną zależność między warunkami meteorologicznymi a produkcją nasion w pewnych okresach rozwoju generatywnego: 1) rok przed zawiązywaniem się pączków kwiatowych, 2) w czasie różnicowania zawiązków kwiatowych, 3) po zapyleniu i 4) w okresie zapłodnienia. W roku poprzedzającym zawiązywanie pączków kwiatowych obradzaniu nasion sprzyja ciepłe

i słoneczne lato, po którym następuje chłodna jesień. Ten okres poprzedzający proces kwitnienia wydaje się być najważniejszy dla późniejszego urodzaju nasion.

Produkcja nasion była wyższa, gdy w roku zawiązywania i rozwoju pączków kwiatowych była słoneczna i sucha wiosna (marzec, kwiecień) oraz ciepłe i słoneczne lato (lipiec), a w następnych latach występowały niskie temperatury tuż po zapyleniu i w okresie zapłodnienia.

Wyniki sugerują, że dla różnych stadiów długiego rozwoju szyszek, jako optymalne wymagane są bardzo różne warunki pogodowe. Taki układ pogody rzadko jest spełniony, stąd dobry urodzaj nasion występuje tylko w niektórych latach. Jednakże w porównaniu ze świerkiem, sosna wykazuje większą tolerancję na warunki pogodowe, o czym świadczą niższe wartości współczynników korelacji między urodzajem szyszek a czynnikami klimatycznymi. To tłumaczy, dlaczego u sosny występuje częściej urodzaj niż u świerka.

ХЕНРЫК ФОБЕР

Зависимость между климатическими факторами и урожаем шишек сосны обыкновенной (Pinus silvestris L.) в Польше

Резюме

Урожай семян сосны (*Pinus silvestris* L.) в 1951 - 1965 годах соотнесли с некоторыми климатическими факторами в течение 42 месяцев, предшествовавших созреванию семян. В результате статистических анализов была обнаружена существенная зависимость между климатическими факторами и продукцией семян в определенные периоды генеративного развития: 1) год до завязи цветочных бутонов, 2) во время дифференциации цветочных завязей, 3) по опылению и 4) в период оплодотворения. В год, предшествующий завязи цветочных бутонов, хорошему урожаю семян способствует теплое и солнечное лето, после которого наступает холодная осень. Этот период, предшествующий процессу цветения, является, по всей вероятности, наиважнейшим для позднейшего урожая семян.

Продукция семян была более высокой, когда в год завязи и развития цветочных бутонов была солнечная и сухая весна (март, апрель), а также теплое и солнечное лето (июль), а в последующие годы были низкие температуры сразу же по опылению и в период оплодотворения.

Результаты предполагают, что для разных стадий длительного развития шишек оптимальным требованием являются разные условия погоды. Однако, такое соотношение погоды бывает редко, отсюда хороший урожай семян бывает только в некоторые годы. Однако, по сравнению с елью сосна более вынослива к условиям погоды, о чем свидетельствуют более низкие значения коэффициентов корреляции между урожаем шишек и климатическими факторами. Это объясняет, почему у сосны хороший урожай бывает чаще, чем у ели.