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Investigations on the bud dormancy of *Populus* × *berolinensis* Dipp.

I. Annual cycle of the shoot apex development

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Woody plants of the moderate climatic zone exhibit an annual rhythmic development manifested in the succession of intermittent periods of growth and dormancy. Previous to the external conditions becoming unfavourable for growth, the elongation of shoots in most trees is inhibited and buds form which, even before the external favourable conditions return, have the ability of sprouting (see review by Kozlowski 1964). These observations led to the supposition that the development rhythm of trees is of endogenic nature as the result of evolutional adaptation to climatic conditions prevailing for a long period, whereas external factors play only a modifying role (see review by Vegis 1965a).

The period of externally noticeable inactivity of the apex, at the time when it is enclosed in a special organ — a bud — has been termed dormancy. In the particular phases of this period the ability of the bud to sprout varies. The opening of buds and growth of shoots may occur after removal of the leaves on the tree within a definite time period after bud setting (Goebel 1880; Späth 1912). This period is usually called „Vorruhe" (Johannsen 1913), summer dormancy (Doorenbos 1953), correlated inhibition (Samish 1954) or the period of latent growth (Sergeyev, Sergeyeva and Melnikov 1961). The absence of growth after removal of the leaves, in spite of favourable external conditions, is considered as the beginning of „Mittelruhe" (Johannsen 1913), winter dormancy (Doorenbos 1953) or rest (Samish 1954), which in natural conditions is broken by the influence of cold (Coville 1920). Nevertheless the tree buds remain inactive in a state known as imposed dormancy (Doorenbos 1953) or quiescence (Samish 1954) until warmer spring weather sets in. In the following text the terms according Samish (1954) will be used. For practical purposes a number of growth-forcing methods have been developed for artificial breaking of dormancy: etherization (Johannsen 1906), warm water bath (Molisch 1909), treatment with various chemical substances (Denny and Stanton 1928) and hormones (see review by Vegis 1965b).

Numerous investigations have been undertaken on bud dormancy, but only in few woody species the phases of dormancy have been distinguished (Johannsen 1906; Molisch 1909; Guzhev 1958; Vogl and Kemmer 1961; Takahashi 1963; Gowin 1965; Pijr 1966).

The present paper is an attempt at a characteristic of the annual cycle of the shoot apex development in *Populus* × *berolinensis* and at establishing the phases of bud dormancy.

MATERIAL AND METHODS

The object of study were twigs from the lower part of the crowns in the zone up to 5 m height from the trunk base of tree about 34 years old with mean height of 21 m.

Observations were made in the years 1962 and 1965. It was noted that in both these years the buds opened in April. After a period of active elongation of the shoots, new buds were set. As symptom of bud setting was considered the absence of further differentiation of leaves and the formation of scales covering the apex. Buds formed first, as early as May, on the short shoots and on the tips of long shoots in June. As the long shoots elongated, buds formed in the leaf axils.

In order to establish the growth ability of buds at various times after their setting, twigs were cut from the trees and placed in conditions favourable to growth. The detached twigs were 2—3 years old, 20—30 cm long, consisting in their upper part of a current year's long shoot (10—15 cm long) with a terminal bud, and in their lower (older) part of one- or two-year-old short shoots (2—6 cm), each ending in a leaf rosette and terminal bud. The twigs were placed in the laboratory in beakers with water and covered with glass bells giving air access from below. The relative air humidity under the bells was 80—100 percent. After 7—10 days an abscission layer was formed on the twigs and the leaves fell. Very seldom single leaves remained attached longer, up to 30 days.

For determining the state of bud dormancy, various treatments breaking dormancy were applied such as defoliation, warm water baths and chilling.

The dates of opening of the particular buds on each twig were recorded at 2—3 day intervals. As a sign of bud opening the appearance of the tip of a green leaf was adopted. The number of twigs subjected to the same experimental treatments was 5, 10 or 20 at each particular date. Sometimes the buds did not burst at all on some twigs and the number of days elapsed from cutting of the twig to visible bud opening varied in the particular treatments. Thus, the results obtained in each experimental combination were characterized in two ways: 1) as the number

of twigs on which the same type of buds opened, and 2) as the mean number of days elapsed from shoot cutting to the opening of these buds. To make the comparison easier, an „index of bud opening" was introduced based on both the above enumerated values. If no bud bursting symptoms were observed up to 70 days and the twig remaining alive, the time of bud opening was considered as infinity (∞). The index was calculated as the reciprocal of the mean harmonic number of days required for the opening of definite buds on the twigs. The value of this index, therefore, denotes the proportion of the total number of buds in the treatment opening per day. The index of bud opening is expressed by the formula:

$$W = \frac{\frac{1}{t_1} + \ldots\ldots + \frac{1}{t_n}}{N}$$

where: t — number of days required for the opening of a definite bud on each twig, N — number of twigs in the experimental treatment.

The index values vary within the range O (no growth) to 1 (opening of buds on all twigs one day after their cutting from the tree). At low t values, the numerical equivalents of the index change rapidly, giving wide differences even when t_1 and t_2 differ only by one day. At higher t values the index changes but little and the differences are slight. In view of this shortcoming of the method the index was used only in comparative elaboration of the final results.

RESULTS

The ability of buds to resume growth after cutting of the twig from the tree

1. Experiments under natural daylight

The cut twigs were placed in the laboratory under natural daylight. The mean temperature of air in the premises was 18 to 20°C in the winter and 23 to 25°C in the summer, the difference between the 24-hrs maximum and minimum not exceeding 3°C. The results of observations on the opening of terminal buds on the long and short shoots in dependence on the date of their cutting are listed in table 1 for the summer, autumn and winter of 1962/1963, and the summer of 1965, as well as in table 4 for the autumn and winter of 1961/1962.

The terminal buds of the long shoots on twigs cut off in the period between the end of June and the end of August opened on only few twigs (in August 1962 buds did not open on any). The time of bud opening on the particular twigs varied widely. From the end of September to mid

Table 1

Bud opening on detached *Populus* x *berolinensis* twigs kept under various photoperiodic conditions

(ND — natural daylight, CL — continuous light, SD — short 10-hr day)

Date of twig collection		Light conditions	No. of twigs in one treatment	Beginning of terminal bud opening			
				long shoots		short shoots**)	
Year	Month and day			no. of twigs	mean no. of days	no. of twigs	mean no. of days
1962		ND	10	5	11	3	13
	June 20	CL	10	7	13	6	15
		SD	10	8	16	3	16
		ND	10	1	6	0	∝
	July 10	CL	10	3	6	0	∝
		SD	10	2	13	3	16
		ND	10	3	18	6	19
	July 21	CL	10	2	16	1	18
		SD	10	5	16	1	17
		ND	10	1	7	2	17
	July 30	CL	10	3	22	2	16
		SD	10	4	16	7	15
		ND	10	0	∝	5	13
	August 10	CL	10	4	11	9	14
		SD	10	3	19	9	14
		ND	10	0	∝	10	21
	September 4	CL	10	2	18	9	24
		SD	10	2	16	3	19
	October 9	ND	10	0	∝	8	26
		CL	10	1	14	9	15
	November 10*	ND	10	0	∝	1	34
		CL	10	5	46	6	35
		ND	10	10	24	10	24
	December 10*	CL	10	10	23	10	23
1963		ND	10	10	18	10	17
	January 10*	CL	10	10	14	10	15
		ND	10	10	16	10	17
	February 9*	CL	10	10	14	10	14
		ND	10	10	11	10	15
	February 26*	CL	10	10	12	10	12
		ND	10	10	9	10	9
	March 11*	CL	10	10	10	10	10
	March 27*	ND	10	10	7	10	8
	April 9*	ND	10	10	4	10	4
		CL	10	10	4	10	4
1965	June 30	ND	20	2	4	13	16
	July 19	ND	20	4	18	7	14
	August 9	ND	20	11	15	9	16
	August 31	ND	20	4	23	6	15
	September 22	ND	20	1	16	9	24

*) leafless trees

**) first bud opening on any short shoot of the twig

November no bud opening was observed. On the branches cut from leafless trees at the end of November, the buds began to grow again and the time required for their opening diminished gradually at the consecutive dates of collection.

The buds on short shoots opened from June to mid September mostly within a similar time (ca. 2 weeks) as did the terminal buds of long shoots, but on a larger number of twigs. This number, however did not exceed one half of all the twigs. On the twigs cut off in September-October 1962, the buds opened on a larger number of shoots than at earlier dates, but after a longer lapse of time (about 3 weeks). At the end of October and in the beginning of November hardly any opened, and from the end of November to April their opening was analogous to that of terminal buds on long shoots.

2. Experiments under controlled photoperiodic conditions

The twigs placed under continuous light received besides normal daylight, continuous light with TELAM — white light fluorescent tubes. Illumination at the night was about 4500 lux. In the same chamber in the period from June to September part of the plants was subjected to short 10-hr day by covering them with black bells from 6 p.m. to 8 a.m. The air temperature was on the average by about 1—2° C higher than under natural daylight. The results for the period 1962/1963 are listed in table 1.

The terminal buds of long shoots on the twigs placed in June-July under continuous light opened similarly as under natural daylength. Buds also burst on some of the twigs cut in August and on single shoots in September and October. From among the twigs cut off in November, buds opened on five, but as late as 46 days after cutting. Beginning with December buds opened on all twigs after a lapse of time similar or somewhat shorter than under normal daylight.

The terminal buds of long shoots on twigs under short day opened like those under continuous light.

The time after which buds opened on the short shoots of twigs exposed to continuous light and short day was similar to the time after which buds of short shoots burst on twigs under natural daylight, but the number of twigs with opening buds varied on short shoots at different dates, without any visible relation to the day-length conditions. The terminal buds of short shoots on the twigs placed in November under continuous light opened more intensively than under natural daylength, similarly as did the buds of long shoots. From December on, the bursting of buds on short shoots of twigs cut at various dates was more rapid or similar to that of the buds under natural daylength.

State of bud dormancy

1. Experiments with defoliation

In the period when the trees had leaves, the latter were removed immediately after cutting of the twigs. The defoliated twigs were placed in 1962 under various photoperiodic conditions, and in 1965 only under natural daylight. The results are compiled in table 2.

Table 2

Bud opening on detached and defoliated *Populus* x *berolinensis* twigs kept under various photoperiodic conditions

(ND – natural daylight, CL – continuous light, SD – short 10-hr day)

Date of twig collection		Light conditions	No. of twigs in one treatment	Beginning of terminal bud opening			
				long shoots		short shoots *)	
Year	Month and day			no. of twigs	mean no. od days	no. of twigs	mean no. of days
1962		ND	10	10	5	7	7
	June 20	CL	10	8	5	7	5
		SD	10	5	7	4	16
		ND	10	10	6	7	8
	July 10	CL	10	10	6	10	7
		SD	10	10	7	6	9
		ND	10	9	6	5	7
	July 21	CL	10	9	6	3	6
		SD	10	9	6	7	6
		ND	10	9	9	8	10
	July 30	CL	10	10	7	10	7
		SD	10	9	7	5	7
		ND	10	8	7	10	8
	August 10	CL	10	5	9	8	11
		SD	10	5	10	6	8
		ND	10	0	∞	7	14
	September 4	CL	10	1	7	6	11
		SD	10	1	14	5	17
	October 9	ND	10	1	68	5	33
		CL	10	2	12	4	21
1965	June 30	ND	20	20	7	4	11
	July 19	ND	20	17	8	7	13
	August 9	ND	20	16	9	16	12
	August 31	ND	20	13	12	17	13
	September 22	ND	20	1	10	8	22

*) first bud opening on any short shoot of the twig

The long shoot terminal buds opened under all photoperiodic conditions similarly: in the period June-July they were numerous and grew rapidly, in August they opened on a smaller number of twigs and within a longer time period. From September on, only one or two twigs developed apical buds.

On the short shoots terminal buds opened in June and July on a smaller number of twigs than did the same buds on long shoots, but within a similar period of about one week. In August bursting buds were more numerous than on the long shoots. Slow opening of buds was also observed in September and October (after ca. 2—3 weeks).

2. Experiments with warm water bath

In the autumn-winter period the detached twigs were subjected to a warm water bath after Molisch (1909), and then placed under natural daylight.

Table 3

Bud opening on detached twigs of *Populus* x *berolinensis* treated by warm water bath of various temperature and duration regimes
Date of collection: November 1965

Water bath temperature, °C	Duration of bath, hrs	Number of twigs		Mean number of days to bud opening
		in one treatment	which started opening terminal buds	
30	12	10	9	34
	18	10	10	24
	24	10	10	18
	30	10	9	24
34	12	10	10	25
	18	10	10	22
	20	10	10	15
	24	9	9	17
38	12	10	10	17
	18	10	10	19
	24	10	1	21

a) Establishment of optimal bath conditions *. At the beginning of November 1965 the twigs were immersed in water of varying temperature (30°, 34°, and 38° C) for various time periods (12—30 hrs). The results, as regards terminal bud opening on long shoots, are presented in table 3. The buds on twigs immersed for 20 hrs in a bath of 34° opened most

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rapidly. The shortest time required for bud break does not indicate, however, the optimum conditions of the bath stimulus. Further observation of shoots after bud break, during their active growth would suggest as optimal conditions a 24-hr bath at 30° the most favourable for growth induction.

In additional experiments the baths of elevated temperature, 45°, 55°, and 65° of 3, 5 and 10 min duration, respectively, were uneffective or caused dying of the twigs.

Table 4

Bud opening on detached *Populus* x *berolinensis* twigs treated by warm water bath. Bath temperature: 1960/1961: 35—39°C, 1961/1962: 32—35°C

Date of collection and bath of twigs	Duration of bath, hrs	No. of twigs in one treatment	Beginning of terminal bud opening			
			long shoots		short shoots **)	
			no. of twigs	mean no. of days	no. of twigs	mean no. of days
Nov. 19, 1960	0	5	0	∞	1	34
	10	5	5	14	5	14
Dec. 20, 1960	0	5	5	23	5	23
	10	5	5	13	5	13
Jan. 31, 1961	0	5	5	13	5	13
	10	5	5	10	5	9
March 14, 1961	0	5	5	4	5	3
	10	5	0	+*	0	+
Sept. 29, 1961	0	10	0	∞	0	∞
	9	10	1	15	7	16
	20	10	10	12	9	13
Oct. 20, 1961	0	10	0	∞	1	27
	9	10	1	13	10	12
	20	10	10	14	8	14
Nov. 20, 1961	0	10	7	56	9	54
	9	10	10	20	10	17
	20	10	9	15	10	14
Jan. 19, 1962	9	10	10	20	10	21
	9	10	10	14	10	12
	20	10	9	12	10	11
March 9, 1962	0	10	10	9	9	8
	9	10	10	8	10	13
	20	10	10	12	7	14

*) buds died
**) first bud opening on any short shoot of the twig

b) *Seasonal observations.* Preliminary experiments were carried out in 1960/1961, in which the twigs were immersed for 10 hrs in a bath of 35—39°. In 1961/1962 the main experiments were performed; the bath

temperature was lowered to 32—35° and its duration was 9 and 20 hrs. The results are shown in table 4. They indicate that in November, December and January 1960/1961 the bath accelerated bud break on long and short shoots as compared to that on twigs not subjected to this treatment, although in January the difference in the rate of bud opening was slight. Twigs treated with baths in March 1961 died. The experiment made in 1961/1962 demonstrated that, whereas the terminal buds of the control long shoots did not open in September and October, those on twigs kept in the bath for 20 hrs started to grow. In November, on the other hand, when the buds on the control shoots began to burst, each bath applied accelerated their opening. Short shoot terminal buds burst in September and October after a 9-hr bath more intensively than those on long shoots. In November and January the difference was only slight. In March both after a 9- and a 20-hr bath the short shoot buds opened slower and were less numerous than on the control twigs. The same buds on twigs bathed for 20 hrs opened similarly as those of long shoots (with the exception of those treated in March). The differences in bud break between the short shoots from treatments of various bath-length were slight. Only the bud break on twigs subjected to a 20-hr bath in September and to a 9-hr bath in March was more rapid.

Table 5

Bud opening on detached *Populus* x *berolinensis* twigs after a period of chilling

Date of collection and beginning of chilling twigs	Duration of chilling, days	No. of twigs in one treatment	Beginning of terminal bud opening			
			long shoots		short shoots**	
			no. of twigs	mean no. of days	no. of twigs	mean no. of days
October 2, 1961	0	10	0	∞	2	46 (46)
	10	10	0	∞	2	41 (51)
	30	10	6	45 (75)*	8	28 (58)
	60	10	10	20 (80)	10	16 (76)
	90	10	10	12 (102)	10	8 (98)
October 4, 1962	0	10	0	∞	8	26 (26)
	30	10	8	30 (60)	8	29 (59)
	45	10	8	25 (70)	8	24 (69)
	60	10	10	24 (84)	10	19 (79)

*) in parenthese mean number of days elapsed from beginning of chilling to bud opening after taking out of refrigerator

**) first bud opening on any short shoot of the twig

2. Experiments with chilling

In order to determine the chilling requirements for breaking bud dormancy, the twigs taken from trees in the period preceding the cool autumn season with mean diurnal air temperature below 10°, were placed

in beakers filled with water and put in a refrigerator with a temperature of 3—5°. After a definite period the twigs were taken out and placed in conditions of natural daylight. In 1961 the defoliated twigs were exposed to low temperature on October 2, whereas in 1962 twigs with leaves were exposed to cold on October 4. They shed their leaves after about 20 days. The results of the experiments are compiled in table 5.

Opening of terminal buds was noted (although very late) on long shoots of some twigs previously subjected to chilling for 30 days. After 60 days of exposure to cold, buds opened on all the branches as early as after 20 days.

The short shoot apical buds opened more numerously and rapidly than those on the long shoots.

DISCUSSION AND CONCLUSIONS

The period of growth of *Populus* x *berolinensis* lowermost twigs was for the long shoots about two and one half months (from April to June), for the short shoots it was less: they exhibited terminal buds already in the beginning of May. This short period of growth of the twigs was due to their situation in the lower part of the crown of high trees (Münch 1938; Serebrakov 1952; Sergeyev, Sergeyeva and Melnikov 1961).

For the remaining part of the year the growth apexes on the twigs were hidden in the buds in a state of dormancy. Conclusions as to this state of dormancy may be drawn on the basis of the reaction of buds on the detached twigs subjected to various experimental treatments, and then placed in the conditions favouring growth (Askenazy 1877; Molisch 1909; Eggert 1961; Kárpatí and Kárpatí 1961; Guzhev 1962).

Experiments with twigs cut from trees at successive dates, and not subjected to any additional treatment, demonstrated that, in the period when the external conditions are favourable to growth, the very fact of cutting of the twig causes a certain number of buds to open (Fig. 1). Removal of leaves on twigs detached in summer caused numerous buds to open rapidly. Only in September no differences were noted in bud break between the twigs with leaves and those defoliated. Observations conducted on the influence of various photoperiodic conditions on the detached twigs did not disclose differences in bud bursting under the daylengths applied in summer. Since, however, the *Populus* x *berolinensis* twigs shed their leaves about 7 days after being cut off, this might have made impossible the reception of the photoperiodic stimulus for which leaves are one of the main receptors (Moškov 1935; Nitsch 1957a; b, Nitsch and Nitsch 1959; Wareing 1954).

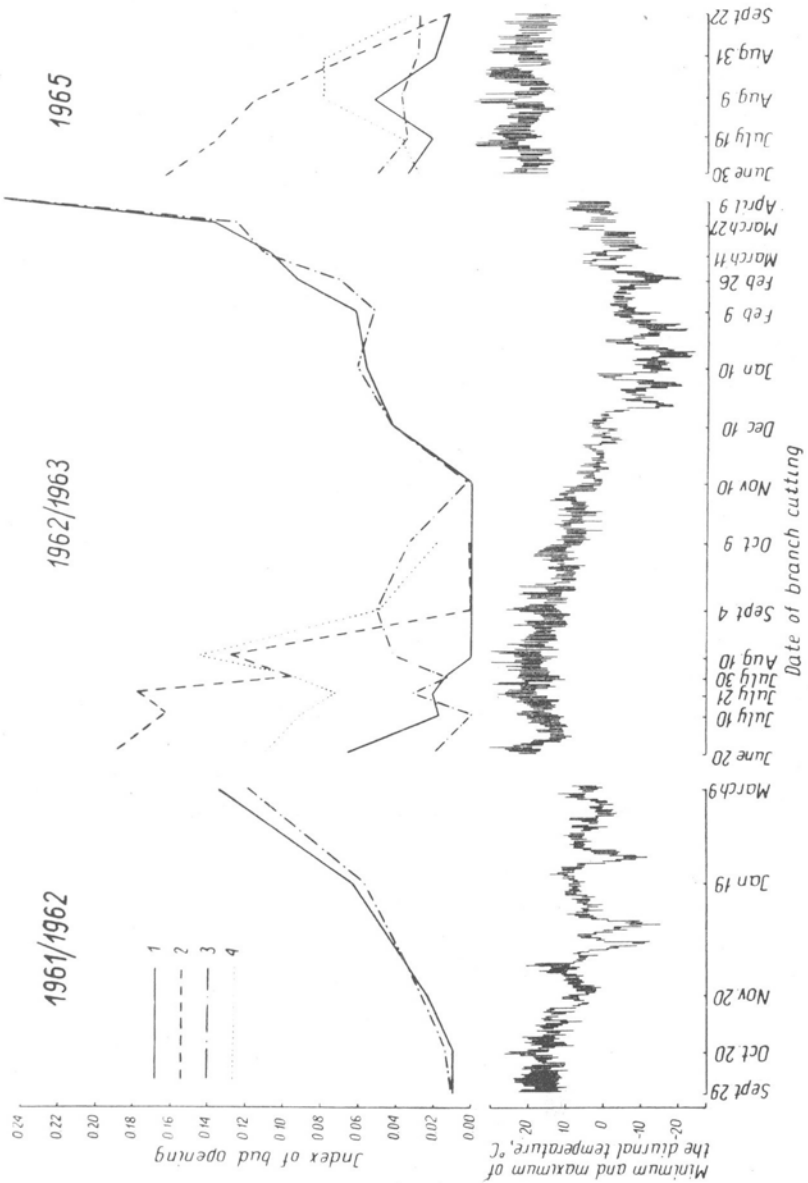

Fig. 1. Opening of terminal buds on long and short shoots of foliated and defoliated twigs cut from *Populus* x *berolinensis* and kept under natural daylight. Minimal and maximal diurnal air temperature values under natural conditions. Mean diurnal air temperature in laboratory conditions 18—20° C. Long shoots: 1 — with leaves, 2 — defoliated; Short shoots: 3 — with leaves; 4 — defoliated

The above mentioned results indicate that from June to August the terminal buds of long shoots, and from May to the end of September those of short shoot of *Populus* x *berolinensis* were capable of growth. Bud growth on the trees was mainly inhibited by the leaves, and partly perhaps also by other influences from the organism of the parent tree. Thus the inhibitory factors were connected with correlative growth inhibition. This part of dormancy may be distinguished as the phase of correlated inhibition of buds.

A lack of ability to bud growth of the twigs cut off from trees observed, as regards long shoots, in the period from September to the beginning of November, and in short shoots from the end of October to November. It should be noted that the September temperature still favoured growth, and the mean air temperature fell below 10° making growth impossible as late as October (Fig. 1). This temperature is considered as the treshold of chilling temperatures (Chandler, Kimball, Philip, Tufts and Weldon 1937; Bulgakova 1937; Lamb 1948; Moroz 1948; Weinberger 1950). This period of cold induced a return of growth ability both in the long and short shoot terminal buds, observed on the detached twigs from the end of November. The results of experiments with artificial chilling of twigs cut off from the trees before the significant autumn temperature decrease demonstrated the dependence of the bud opening rate on the length of the period of chilling, in conformity with the observations of other authors (Moroz 1948; Bennett 1950; Eggert 1951; Pieniążek and Wiśniewska 1958; Weinberger 1961). About 60 days of exposure to a constant temperature of 4° is required in order to obtain uniform bud opening on *Populus* x *berolinensis*. The short shoot buds opened more numerous and faster than those of long shoots. This would indicate that their dormancy is not very deep. It was shown that the number of days elapsed between cutting of the twigs and the date of bud break of long shoot buds on twigs after 30 and 60 days of chilling was similar, whereas after 90 days of cold it was longer. Nevertheless, since bud break after 90 days of chilling was faster than after 60 days, it may be considered that even a period of cold exceeding 60 days had a positive influence as regards breaking of dormancy, although it is possible that in the end period, bud opening was only limited, as has been reported in reference to other species (Chandler and Tufts 1934; Kriebel and Wang 1962; Witkowska-Żuk, Gowin, and Kukiełka 1964).

In the period when the buds on the detached twigs did not open, their dormancy could be broken by a warm water bath of appropriate temperature and length. For *Populus* x *berolinensis* the optimal condition for breaking dormancy and stimulating bud growth was: a 24-hr of water-bath with a temperature of 30°, similarly as for other poplar species (Vogl and Kemmer 1961).

The results of the experiments performed indicate that the terminal buds of long and short shoots were from September to October in a phase of rest; respectively, they were incapable of growth and could only open after application of an agent which acts on the bud breaking its dormancy.

Investigations on the state of bud dormancy which was evaluated on the basis of the reaction of buds to a water-bath applied at various dates under similar conditions (Vegis 1961; Vogl and Kemmer 1961; Takahashi 1963) demonstrated that rest was most difficult to break, i.e. deepest, from the end of September to the second half of October. Results of the same experiments proved also that, for breaking the dormancy of short-shoot buds, a weaker stimulus — a shorter lasting bath — suffices as compared to that necessary in the case of long-shoot buds. It may be affirmed, that the period from the end of September to the second half of October was the middle part of the phase rest.

Beginning with the end of November both long and short shoots recovered their ability for growth. Treatment of the twigs with a water-bath at this period rather accelerated their development than broke their dormancy which was abolished by the previous period of chilling. The period November-December corresponded to the stage of emergence from the phase of rest.

On the twigs cut off in the phase of rest and placed under continuous light, the buds started to grow as early as November, whereas under natural light this occured as late as December. This might have been connected with the direct reception of the photoperiodic stimulus on the buds (Jost 1894; Klebs 1914; Bulgakova 1937; Gustafson 1938; Wareing 1953, 1954) or with their warming, since the air temperature under continuous light was higher by about 1—3°. This supposition seems to be confirmed by the fact that in August and September a similar bud development as under continuous daylight was observed under thermally analogous conditions of short day.

Beginning with December, the shorter was the period between the successive dates of twig cutting and the spring bud break on the trees, the faster occured the opening of the buds and the greater was the number opening, similarly as has been observed in other tree species. Only unfavourable external conditions in nature limited the opening of buds fully capable of growth. As shown by the results of experiments with a water bath in this period, this treatment not only did not accelerate bud break, but it even was noxious to the buds. This would prove that with emergence from rest the buds lost their high resistivity to external conditions. The period from January to spring is a phase of quiescence.

The buds on the short shoots of twigs subjected to bath in March suffered injury easier than the long shoot terminal buds. This is an additional indication of their less deep or shorter-lasting dormancy. This confirm the opinion of Chandler (1942) and Vogl (1964) that the

dormancy of short shoot buds or axillary buds in the lower part of the plant is less deep.

The system of bud dormancy here presented for *Populus* x *berolinensis* is similar to four varieties of the black poplar (V o g l and K e m m e r 1961). However, probably on account of the different age of the trees from which twigs were taken for study, and perhaps also owing to the different conditions prevailing in the laboratory, wide differences were observed in the intensity of bud opening. As compared with the results obtained by a similar method in *Populus nigra* cv. *Italica* (G o w i n 1965), the buds of *Populus x berolinensis* exhibited a far more pronounced phase of rest.

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SUMMARY

From the lower part of the crowns of *Populus* x *berolinensis* Dipp. trees twigs were cut after the end of growth of their long shoots. In order to determine the state of bud dormancy, the detached twigs were placed in conditions favourable to growth under various daylenght and subjected to various treatments breaking dormancy, as defoliation, warm water bath and chilling.

In the annual cycle of the poplar shoot apex development the period of growth (from April to June for long shoots or from April to the beginning of May for short shoots) and the period of dormancy when on the shoot apexes buds were present (during the remaining part of the year), could be distinguished.

In the period of dormancy the following phases were distinguished: the correlated inhibition phase from June to August for terminal buds of long shoots and from May to September for the buds of short shoots. The phase of rest from September to December and from October to December for the buds of long and short shoots, respectively, with in the midle stage of rest from the end of September to mid November and in the stage of emergence of rest from November to December. The phase of quiescence from January to the spring initiation of bud bursting on trees.

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LITERATURE

A s k e n a z y E., 1877, Über die jährliche Periode der Knospen. Bot. Zeit. 35 (50, 51, 52): 793—848.

B e n n e t t J. P., 1950, Temperature and bud rest period, Calif. Agric. 4(1): 11, 13, 15—16.

Bulgakova Z. P., 1937, Vlijanie dliny dnia na raspuskanie pokojaščichsia poček u drevesnych rastenij, Bot. Žurn. 22(5): 413—419.

Chandler W. H., 1942, Deciduous Orchards. Lea and Febiger, Philadelphia.

Chandler W. H., Tufts W. P., 1934, Influence of the rest period on opening of buds of fruit trees in spring and on development of flower buds of peach trees, Proc. Am. Soc. Hort. Sci. 30: 180—186.

Chandler W. H., Kimball M. H., Phillip G. I., Tufts W. P., Weldon G. P., 1937, Chilling requirements for opening of buds on deciduous orchard trees and some other plants in California, Calif. Agr. Expt. Sta. Bull. 611: 1—63.

Coville F. V., 1920, The influence of cold in stimulating the growth of plants, J. Agr. Res. 20: 151—160.

Denny E. E., Stanton E. N., 1928, Chemical treatments for shortening the rest period of pot-grown woody plants, Am. J. Bot. 15: 327—335.

Doorenbos J., 1953, Review of the literature on dormancy in buds of woody plants, Meded. van de Landbouw. te Wageningen (Nederland) 53(1): 1—24.

Eggert F. P., 1951, A study of rest in several Varieties of Apple and in other fruit species grown in New York State, Proc. Am. Soc. Hort. Sci. 57: 169—178.

Goebel K., 1880, Beiträge zur Morphologie und Physiologie des Blattes, Bot. Zeit. 38: 753—760, 769—778, 785—795, 801—816, 817—826, 833—845.

Gowin T., 1965, Badania nad okresem spoczynku topoli piramidalnej, Zesz. Nauk. SGGW — Leśnictwo 7: 39—54.

Gustafson F. G., 1938, Influence of the length of day on the dormancy of tree seedlings, Plant Physiol. 13: 655—658.

Guzhev J. L., 1958, O periode pokoja u plodovych rastenij, Tr. Inst. Genet. A. N. SSSR 24: 195—204.

Guzhev J. Ł., 1962 Značenije temperaturnogo i svetogogo faktorov v prochozdenii drevesnymi porodami perioda pokoja., Tr. Inst. Genet. A. N. SSSR 29: 149—155.

Johannsen W., 1906, Das Aethervetrfahren beim Frühtreiberei mit besonderer Berücksichtigung der Fliedertreiberei. Jena.

Johannsen W., 1913, Ruheperioden, Handwörterbuch der Naturw. Bd. VIII: 514—519.

Jost L., 1894, Über den Einfluss des Lichtes auf das Knospentreiben der Rothbuche, Ber. deutsch. bot. Ges. 12: 188—197.

Kárpatí V., Kárpatí I., 1961, Winter dormancy of Hungarian trees and shrubs. I. Trees and shrubs of natural growes, Acta biol. Acad. Scient. Hung. 11(4): 359—385.

Klebs G., 1914, Über das Treiben der einheimischen Baüme speziell der Buche, Abhand. Heidelb. Akad. Wiss. Math-Nat. Kl. (3): 1—116.

Kozlowski T. T., 1964, Shoot growth in woody plants, Bot. Rev. 30(3): 335—392.

Kriebel H. B., Wang C. W., 1962, The interaction between provenance and degree of chilling in bud-break of sugar maple, Silvae Genet. 11(5/6): 125—130.

Lamb R. C., 1948, Effect of temperatures aboves and below freezing on the breaking of rest in the Latham Raspberry, Proc. Am. Soc. Hort. Sci. 51: 313—315.

Molisch H., 1909, Das Warmbad als Mittel zum Treiben der Pflanzen, Sitzber. d. Kais. Akad. d. Wiss. Wien. Bd. CXVIII, Abt. I.

Molisch H., 1930, Pflanzenphysiologie als Theorie der Gärtnerei, Jena.

Moroz E. S., 1948, Eksperimentalno-ekologičeskije issledovanija perioda pokoja u drevesnych rastenij, Eksperim. Bot. 6: 295—331.

Mošков B. S., 1935, Rol listev v fotoperiodičeskoj reakcii rastenij, Tr. po prikl. bot., genet. i selek., Socjalističeskoje Rastenevodstvo 15: 25—30.

Münch E., 1938, Untersuchungen über die Harmonie der Baumgestalt, Jahrb. f. Wiss. Bot. 86: 581—673.

Nitsch J. P., 1957a, Growth response of woody plants to photoperiodic stimuli, Proc. Am. Soc. Hort. Sci. 70: 512—525.

Nitsch J. P., 1957b, Photoperiodism in woody plants, Proc. Am. Soc. Hort. Sci. 70: 526—544.

Nitsch J. P., Nitsch C., 1959, Photoperiodic effects in woody plants: evidence for the interplay of growth-regulating substances. [In:] Photoperiodism and Related Phenomena in Plants and Animals: 225—242.

Pieniążek J., Wiśniewska J., 1958, Studia nad okresem spoczynku zimowego siewek Antonówki, Prace Inst. Sad. 3: 130—147.

Pijr R., 1966, O godičnom cikle razvitija poček u drevesnych porod. Tartu Ülikooli toimetised, Uč. zap. Tartusk. Univ. 185: 116—122.

Samish R. M., 1954, Dormancy in woody plants, Ann. Rev. Plant Physiol. 5: 183—204.

Serebriakov I. G., 1952, Morfologija vegetativnych organov vyssich rastenij, Moskva.

Sergeyev L. I., Sergeyeva K. A., Melnikov V. K., 1961, Morfo, fiziologičeskaja periodičnost i zimostojkost drevesnych rastenij, Ufa.

Späth H. L., 1912, Der Johannistrieb. Ein Beitrag zur Kenntnis der Periodizität und Jahresringbildung sommergrüner Holz-Gewächse, Berlin.

Takahashi N., 1963, Studies on the promotion of sprouting and breaking of dormancy in winter buds of *Cornus controversa*, Japan J. Bot. 18(2): 169—197.

Vegis A., 1961, Samenkeimung und vegetative Entwicklung der Knospen. [In:] Encyclopedia of Plant Physiology, ed. by W. Ruhland, Springer Verlag, Berlin XVI: 168—298.

Vegis A., 1965a, Ruhezustände bei höheren Pflanzen. Induktion, Verlauf und Beendigung: Übersicht, Terminologie, allgemeine Probleme. [In:] Encyclopedia of Plant Physiology, ed. by W. Ruhland, Springer Verlag, Berlin XV(2): 499—533.

Vegis A., 1965b, Die Bedeutung von physikalischen und chemischen Aussenfaktoren bei der Induktion und Beendigung von Ruhezuständen bei Organen und Geweben höherer Pflanzen. [In:] Encyclopedia of Plant Physiology, ed. by W. Ruhland, Springer Verlag, Berlin XV(2): 534—668.

Vogl M., 1964, Die autonome Winterruhe in verschiedenen Knospen und Organen der Pappel, Arch. Forstw. 13(2): 169—175.

Vogl M., Kemmer Ch., 1961, Untersuchungen zur Winterruhe bei Pappeln, Arch. Forstw. 10(8): 872—895.

Wareing P. F., 1953, Growth studies in woody species. V. Photoperiodism in dormant buds of *Fagus sylvatica* L., Phys. Plant. 6(4): 692—706.

Wareing P. F., 1954, Growth studies in woody species. VI. The locus of photoperiodic perception in relation to dormancy, Phys. Plant. 7(2): 261—277.

Weinberger J. H., 1950, Chilling in requirements of peach varieties, Proc. Am. Soc. Hort. Sci. 56: 122—128.

Weinberger J. H., 1961, Temperatures and fruits and seeds. [In:] Seeds, The Yearbook of Agriculture: 46—51, U. S. Dept. Agr., Washington.

Witkowska-Żuk L., Gowin T., Kukiełka A., 1964, Obserwacje nad okresem spoczynku zimowego u kasztanowca, lipy i klonu. Rocznik Sekcji Dendrol. PTB 28: 121—132.

Badania nad spoczynkiem pączków topoli berlińskiej (Populus × berolinensis Dipp.)

I. Roczny cykl rozwojowy wierzchołka wzrostu pędu

Streszczenie

Po zakończeniu okresu wzrostu i wykształceniu pączków wierzchołkowych na długopędach gałązek w dolnym piętrze koron około 34-letnich drzew topoli berlińskiej (*Populus* × *berolinensis* Dipp.) ścinano z drzew gałązki, które 1) umieszczano w sprzyjających do wzrostu warunkach w celu określenia jaka jest zdolność pączków do rozwinięcia w różnym czasie od momentu ich założenia i 2) poddawano działaniu różnych czynników przerywających spoczynek: defoliacji, ciepłej kąpieli wodnej, sztucznemu przechłodzeniu, w celu określenia głębokości spoczynku.

W rocznym cyklu rozwojowym wierzchołków wzrostu badanych gałązek topoli berlińskiej wyodrębniono dwa okresy:

1. Okres wzrostu — od kwietnia do czerwca dla wierzchołków długopędów i od kwietnia do początku maja dla wierzchołków krótkopędów.
2. Okres spoczynku (przez pozostałą część roku) — kiedy na wierzchołkach pędów znajdowały się organy spoczynkowe — pączki.

W okresie spoczynku wyróżniono następujące fazy:

A. Faza spoczynku względnego od czerwca do sierpnia dla pączków wierzchołkowych długopędów i od maja do września dla pączków krótkopędów. Wzrost w pełni zdolnych do rozwoju pączków był uniemożliwiony przez wpływ czynników związanych z korelatywnym hamowaniem wzrostu.

B. Faza spoczynku głębokiego od września do grudnia dla pączków długopędów i od października do grudnia dla krótkopędów. Pączki mogły podjąć wzrost dopiero po przerwaniu spoczynku przy pomocy działania na pączek ekstremalnych czynników zewnętrznych, takich jak długotrwałe przechłodzenie lub ciepła kąpiel wodna.

a. W stadium środkowym spoczynku głębokiego d końca września do połowy listopada, pączki nie rozwijały się bez przerwania spoczynku.

b. W stadium ustępowania spoczynku głębokiego od listopada do grudnia pączki pod wpływem naturalnego przechłodzenia odzyskiwały stopniowo zdolność do rozwoju.

C. Faza spoczynku narzuconego od stycznia do zainicjowania wiosennego rozwoju pączków na drzewach. Rozwój pączków był hamowany jedynie przez niesprzyjające warunki zewnętrzne. Pączki miały mniejszą odporność na wpływ czynników zewnętrznych, łatwiej ulegały uszkodzeniom.