Growth and development of shoot apex in barley
II. Distribution of growth rates during vegetative phase

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Abstract

The changes in the volume of the apical dome and of the frusta indicate that the mean relative rate of volume growth of the whole apical dome is much higher than in the first frustum which, in turn, grows much faster than the next one. It was found in studies of the distribution of mitoses and of cell arrangement that the volume relative growth rate of the distal part of the apical dome is at least 5-10 times slower than that at the level of new leaf primordia initiation.

conditions such as temperature, the studies could be performed on seedlings under conditions not strictly controlled.

MATERIAL AND METHODS

The main investigations were carried out on the spring barley variety 'Damazy' from the 1977 harvest, seeded at the beginning of October 1978. Suplementary studies were performed on seedlings cultured at other dates. The caryopses were soaked for 24 h at room temperature in well oxygenated water which was changed several times. Then they were placed groove downwards on a soil layer in a container and covered with a layer of about 2 mm sand so that the sprouts would be visible as soon as they appear. The container was placed on a window sill exposed to the south. Ambient temperature at the moment of seeding was in September 1978 around 22°C, but it was not constant. In order to obtain plants in the same developmental phase the seedlings were selected; the caryopses germinating earliest (in the second half of the day of sowing) were discarded. Most caryopses started germinating at the beginning of the third 24 h. Part of the germinating plants was taken for examination as the first harvest, most, however, were left. Seeds which did not germinate were discarded. After the next two 24-h periods seedlings differing in size from the most numerous group were removed and a new batch was taken for study. The same procedure was repeated every 48 h, until the plants reached the generative phase (after 10 days) and then every day (since from this term plants were derived on which quantitative growth investigations of the apex in generative phase described in a forthcoming paper were performed). The apical part of the shoot comprising the apical dome and 3-5 of the youngest frusta was prepared out from the plants under a magnifying glass. From each batch 6 apices were photographed *in toto* and *in vivo* as described in the preceding paper and about twenty were taken for studying the mitoses. From these harvests apices were partly taken for the anatomical examinations previously described. During preparation the number of leaves or leaf primordia removed was recorded and the approximate plastochron age of the apex was determined as follows. To the number N of existing leaf primordia $n \times 0.25$ was added, where n — one of the values between 1 and 4. The choice of this number depended to which age group the apex was classified. The apices could be divided, with some experience, into four groups according to the size of the youngest leaf primordium and the height of the apical dome. The 4th group with N primordia differed from the first one with $N + 1$ primordia usually only by the lack of a noticeable bulge at the site of the $N + 1$ leaf primordium. To this group were classified apices aged

N + 1 (whole number). It should be mentioned that in the case of barley, in view of the development of its apex, one cannot rely on the plastochron index determined by the method of Erickson and Michelin (1957) because of the unrepeatability of the history of the particular leaves (the logarithms of the lengths of successive leaves as the function of time do not give parallel straight lines, particularly in early development phases).

Preparation of material for mitoses distribution study

The prepared out part of the shoot apex was fixed in an ethanol-acetic acid mixture (3:1) at 0°C for 4-12 h. After washing with distilled water the material was placed in a water bath at 60°C for 10 min in 1 N HCl. Hydrolysis was interruped by addition of cold water. The material after washing was stained with Schiff's reagent for 8-12 h (at room temperature in darkness) washed with bisulphite solution for 10 min and then with distilled water for half an hour and passed through glycerin. Under the magnifying glass the part with the apical dome and 2 youngest leaf primordia was cut off. The apex was placed in a glycerin film on a slide so that the median plane would be parallel to the slide surface. The whole was covered with a coverslip. When observing the apex under the magnifying glass, the coverslip was lightly pressed down to flatten it slightly. Then the coverslip was delicately lifted. The flattened apex adhered to one of the glasses. It was dehydrated with ethanol flowing over the surface of the slanting slide from a pipette for 5 min. Then the apex was embedded in Euparal. The central axial optic section through the apex was photographed with the use of a $\times$ 63 objective. After obtaining the positive in a $\times$ 710 magnification, the central optic section through the apex was analysed under an immersion microscope $\times$ 100 and the places where mitoses were visible on the optic cross section were marked on the photograph. The mitoses were mapped from metaphase to late anaphase. From the marked photographs (10 for each development phase) a summated map of mitoses distribution was prepared.

RESULTS

The relation between the plastochron age of the apex and the calendar age is dependent on the conditions of development, as illustrated by Fig. 1. Always, however, the successive plastochrons are found to be shorter. Fig. 2 shows a diagram of caulis growth as the function of plastochron age, prepared on the basis of analysis of 64 apices photographed *in toto*. The apex outline shown on the left represents apices of embryos at the beginning of germination. The plastochron age of this apex was evaluated as 4.5. The outline on the right is an apex at the beginnig of generative phase and plastochron age 9.25. The diagonal lines represent the limits of frusta. During development they move away from the apex. The figures on the horizontal axis corresponding to the level of the apex top indicate the plastochron age. The apical dome begins, towards the end of each plastochron, when a new bulging primordium appears, to lose its basal part which is added to the caulis as a new frustum. However, the apical dome shares the increment of its volume between itself (reinvestment) and the newly formed frustum. The previous frustum is then aged one plastochron, the next one two and so on. The frustum from the axil of leaf 4 to that of leaf 5 is denoted 5, the next one 6 etc, (figures between slanting lines in Fig. 2). Frustum 5 was formed in plastochron 5. Thus, the age of the frustum is equal to difference between the number characterizing the present plastochron age of the apical dome with 1 added and the figure characterizing the number of the given frustum. The difference in the height of the frustum at the beginning and end of a plastochron is the increment in height of this frustum in the given plastochron. Heigh increment of the apical dome is expressed in the same way. The latter

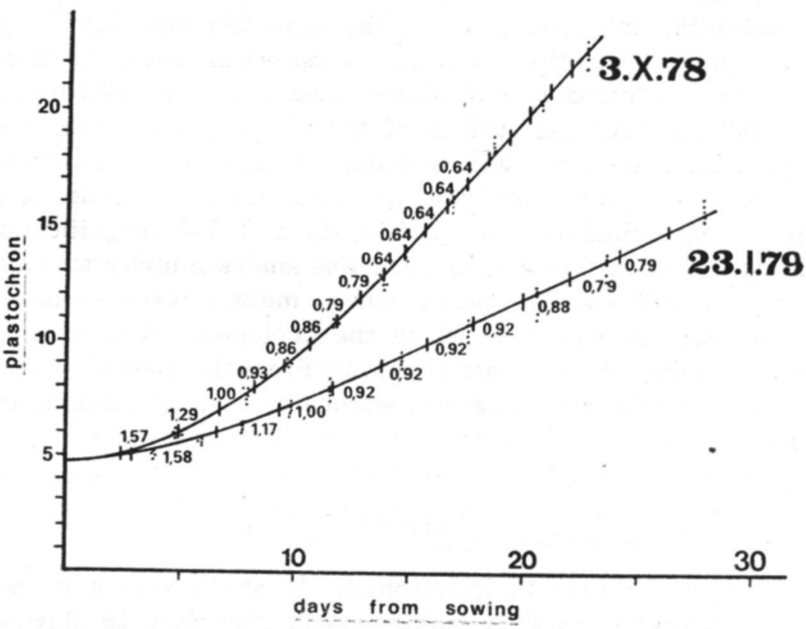

Fig. 1. Relation between plastochron age and calendar age in two seedling populations growing at different absolute rates. The figures at the curves indicate the relation between the duration of the given plastochron and that of plastochron 8 (from 7 to 8). Data of seeding are given

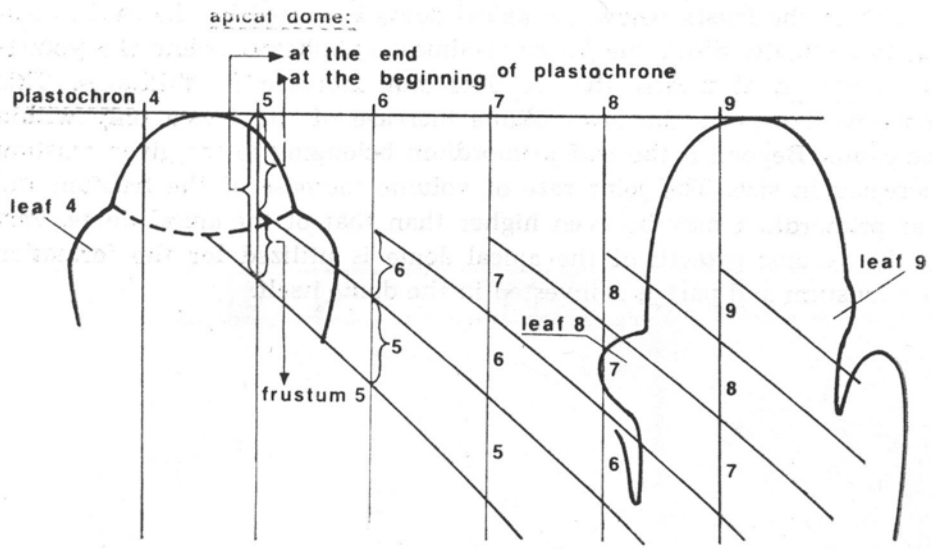

Fig. 2. Diagram of caulis growth in *Hordeum* plotted on the basis of analysis of the age and dimensions of 64 apices photographed *in toto* and *in vivo* (see text)

grows relatively fast, whereas the frustum elongates only in the course of the first plastochron of its existence. When it reaches the age of plastochron 5 it again starts elongating in connection with internode formation.

Mean volume growth rate of the dome and frusta

Assuming a constant shape of the caulis profiles (as shown in Fig. 3 of the foregoing paper: Hejnowicz, Włoch, 1980), we calculated on the basis of the diagram (Fig. 2) the changes in volume of the apical dome and frusta. In calculation of the volume the formula used for the volume of a figure of revolution formed by the revolution of line r = = f(z) around the axis z was used:

$$V = \Pi \int_{0}^{z} r^2 \, dz = \Pi \int_{0}^{z} F(z) \, dz \quad \text{where } F(z) = [f(z)]^2,$$

and from the properties of the integer it was calculated as the area circumscribed by line F multiplied by Π. The diagram y = F(z) was plotted and the surface area under the line F(z) was planimetrically measured. By dividing the volume increment of the apical dome or the frustum in the course of one plastochron by its mean volume, the mean volume relative growth rate was obtained (Table 1). The mean volume relative growth rate for the apical dome is higher than that for youngest frustum which in turn grows faster than the next one. The slow growth of the frusta below the apical dome is caused by the caulis ceasing to elongate. Since the latter is almost cylindrical below the youngest metamer, it means that it does not increase in thickness. This concerns, however, the low volume increase of the frusta only within the caulis. Beyond it the leaf primordium belonging to the given frustum increases in size. The joint rate of volume increase of the frustum and leaf primordium may be even higher than that of the apical dome. Part of the volume growth of the apical dome is utilized for the formation of a frustum and part is reinvested in the dome itself.

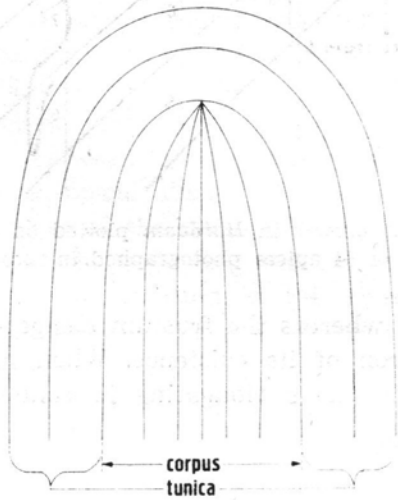

Fig. 3. Diagram of displacement lines — i.e. of tracks along which the elements of the cell wall network of the apex are shifted during growth

Table 1

Mean relative growth rate of volume

Plastochron	Per plastochron during one plastochron				Per day during one plastochron			
	6	7	8	9	6	7	8	9
Apical dome	1.016	0.773	0.740	0.628	0.462	0.429	0.525	0.483
Frustum I	0.148	0.307	0.290	0.370	0.067	0.171	0.207	0.285
Frustum II		0.133	0.060	0.070		0.074	0.043	0.054

When calculating the relative rate of volume increase of the whole apical dome, its volume increment was divided by the whole volume. It is to be expected, however, that the relative rate of growth may not be uniformly distributed in the apical dome. There is only one possibility: the part at the tip grows slower than the proximal part. If so, the relative growth rate at the level of leaf primordia formation is

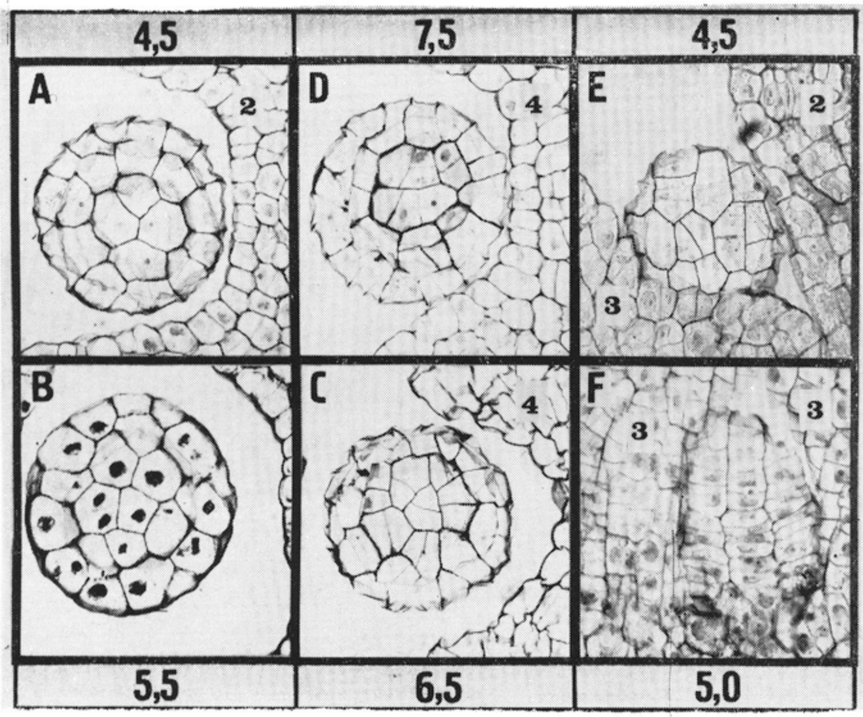

Fig. 4A-F. Cross-tangential section through first layer of tunica in distal part in the successive plastochrons

A — in germinating seedling, plastochron 5. B, C, D, — plastochrons 6, 7, 8, respectively. E-F corresponding tangenutial sections on apex side at base of apical dome. See description in text higher than the calculated mean rate, thus, at this level the relative growth rate would be maximal. Before analyzing the distribution of the relative growth rate, however, we must discuss the arrangement of cells in the apex.

Distribution of growth rate in the apical dome on the basis of cell arrangement

The lack of periclinal divisions in the cells of the first tunica layer and in the initials of the second layer (Hejnowicz, Włoch, 1980) indicates the absence of linear growth there along the axis within the tunica. Longitudinal growth along the axis occurs, however, at the top of the corpus. Both tunica layers grow only along two dimensions as does the surface of the corpus, since they cannot slip over the surface of the latter. The displacement lines, that is the tracks along which the cell wall network shifts (Schüepp, 1966; Hejnowicz, 1980) can be outlined according to the cell arrangement (Fig. 3). Within the tunica these tracks follow a course parallel to the surface of the apex and they run from the intersection points of the tunica with the axis.

Very interesting are the views of cell walls within the tunica as seen on sections tangential to the surface (transversal in the periaxial part of the apical dome). At the beginning of germination all apical dome cells have walls of equal thickness. During growth of the apex new partitions are introduced which are thinner so that groups of cells derived from particular cells existing in the embryo can be recognized. Fig. 4A-D shows the cross section at the level of the first tunica layer in the successive plastochrons. Examination of such cross sections indicates that the tunica cells in the part close to the tip increase their dimensions meridionally but at most 50 per cent after germination during three plastochrons (Fig. 4-D as compared with A), whereas the cells along the side of the apex at the basis of the apical dome exhibit a 4-fold increase of this dimension from starting germination to the end of plastochron 5.

Fig. 4E shows a longitudinal section passing the surface cell layer on the side of the leaf 4 primordium, made after germination, when the apex began to elongate at the level of this primordium. Longitudinally stretched cells with newly formed transverse partition are visible. Fig. 4F is a longitudinal section through the surface cell layer of the apical dome over the leaf 3 axil at the stage corresponding to the end of plastochron 5 (when the bulge for primordium 5 started). Long groups of cells are visible which formed from those existing in the embryo.

Comparison of meridional growth rate may be also done in the apical and basal part of the apical dome in the following way. In the course of the first three plastochrons the meridional growth of the apical dome is such that the axis of the 4th leaf is displaced to a distance equal to the 2.5-fold meridional dimension of the initial dome as can be estimated from the diagram in Fig. 2 while the meridional dimension at the top increases only for 50 per cent during this interval. The rate of meridional growth in the part close to the top is, thus, much lower than the mean rate of growth of the whole meridional dimension. The slower growth of the top part must, therefore, be compensated by a faster growth in the remaining parts. It results from these data that the supposition that the apex grows at equal volume relative growth rate should be rejected. In order to gain a better knowledge of this distribution, the mitoses distribution in the apical dome was investigated.

Mitosis distribution and volume relative growth rate

Distribution of mitoses was determined on optic axial cross sections through apices prepared by the Feulgen method *in toto* as permanent preparations. This method was found to be applicable to barley plant apices, owing probably to their relatively small diameter and well staining chromosomes. The focus depth of the optic cross section comprised 1-2 cells in dependence on their dimensions. In order to avoid error in determination of the density of mitoses, the microscope was set at the axial level in the following way: the lowest and highest levels in the apex were found and then the adjusting knob of the stage was set at an intermediate level. During analysis of the picture the position of the objective was not changed. For each apex only one optical cross section was examined. The earlier taken photograph of the optical cross section of the given apex allowed precise localisation of the mitosis observed. Fig. 5 shows the zones into which an apex was divided, their limits were guided along the orthogonal trajectories of the displacement line. The centre of the bulge of the leaf primordium no. 5 fell more or less to the border between zones 4 and 5, and in the case of primordium 8 to the lower border of zone 5. The sum of mitoses on the central optical cross section of 10 apices at the given stage of development is listed in Table 2. The number of mitoses N in a zone was converted to the number D proportional to the mean density of mitoses as follows. The mean cell volume, v, in the zone was determined on microtome longitudinal and cross sections through the apices and the surface area of the zone on the axial cross section as were determined. The ratio — v/s was calculated multiplied by N to obtain value D proportional to the density of mitoses in the zone. The volume of the zone in the apex layer comprised in the picture of the central optical cross section is, namely, proportional to s, and the number of cells in this volume is inversely proportional to v. The results are shown in Table 2. The absolute value to mitoses density in the zone was not determined since the thickness of the layer comprised in the optical cross section is diffuse, for simplicity however the number will be referred to as mitosis density. It should be noted that the mean cell volume decreases in the apical dome during its development. Mitosis density is distinctly lower

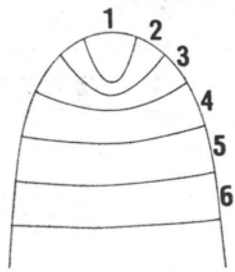

Fig. 5. Diagram of apex division into zones on central longitudinal section

in the parts close to the top, this indicating that mitoses in the cells of this zone are less frequent. If we assume that the duration of mitosis in various parts of the apex is equal, in spite of differences in the frequency of their occurrence, we arrive at the conclusion that cells in the top zones divide more rarely, that is the duration of the whole mitotic cycle is longer there. The duration of the mitotic cycle is proportional to the cell volume doubling time, and the latter is inversely proporional to the volume relative growth rate. Thus, we reach the conclusion that the relative growth rate in the distal part of the apical dome is lower than in the basal part at the level of leaf primordia formation. In zone 6 containing the second frustum counting from the top, the relative growth rate decreases. The rapidly growing zone at first moves away from the top and then, in the period of transition to the generative phase, it moves closer to it. If the distribution of mitoses in the apices is compared at various phases of the same plastochron, it seems that the distal zone with low density of mitoses does not change its dimensions, whereas, the dimension of the basal zone of high mitoses density increases with the increase of the volume of the apical dome as a whole. If the above advanced assumption is not correct, the only other issue would be a prolongation of mitosis duration with the protraction of the mitotic cycle. This would mean that the true volume growth rate in the distal zone as compared with that in the basal part of the apical dome is still smaller than the calculated under the mentioned assumption. It is, therefore, reasonable to believe that there exists at least such

Table 2

Density of mitoses in the zones of the apical dome on the basis of mitoses observed on the central optical sections of 10 apices

	At the plastochron age											
	5.0			6.5			7.5			8.5		
Zone	Number of mitoses	V*	D**	Number of misotoses	V*	D**	Number of mitoses	V*	D**	Number of mitoses	V*	D**
1	1	0.66	0.58	2	0.66	1.17	2	0.45	0.80	1	0.45	0.40
2	3	0.66	1.71	4	0.66	2.28	4	0.40	1.38	6	0.40	2.07
3	10	0.68	4.66	7	0.68	3.26	6	0.48	1.64	15	0.40	4.11
4	16	0.47	4.18	17	0.47	4.44	16	0.28	2.49	22	0.28	3.42
5	31	0.34	6.20	30	0.34	6.00	28	0.27	4.45	30	0.27	4.76
6	15	0.34	3.29	17	0.34	3.73	15	0.20	1.94	36	0.20	4.65

* — Number proportional to cell volume in the zone
** — Number proportional to the density of mitoses in the zone

a volume growth rate increment in the successive zones (from the top) as the increase of the value D shown in the table, that is the growth rate in zone 1 is 5-10 times lower than in the basal part.

DISCUSSION

The empirical basis for determining the relative radial growth rate (PGR_{rad}) in the shoot apex may vary; the calculations may be based on one of the forms of the following transformation:

$$RGR_{rad} = \frac{1}{r}\frac{dr}{dt} = \frac{d\ln r}{dt} \simeq \ln R_{n+1} - \ln R_n = \ln \frac{R_n + 1}{R_n}$$

where r — radius of the apex, R_n — radial distance from the apex axis to the centre or axil of the leaf primordium n, R_{n+1} — the radial distance of the next primordium located further from the tip. The last transformation (on the right) is correct if the pattern of change in dimension in the successive frusta at increasing distance from the tip represents the pattern of changes which occur in the development of a single frustum during successive plastochrons. The ratio $\frac{R_n+1}{R_n}$ is known as the plastochron ratio. The latter was used for determining RGR_{rad} by Richard (1951), Berg and Cutter (1969), Evans and Berg (1971), Smith and Rogan (1975), Williams (1975), Cannel (1978), Gregory and Romberger (1972a, b). When the above named condition is not fulfilled, the middle transformation can be utilized, that is the calculation may be based on the lnr derivative in dependence on time (Rogan, Smith, 1974). If the cross section through the frustum is circular, the double RGR_{rad} gives the relative growth rate in the area of the plane of the cross section. In order to obtain the relative volume growth rate, beside RGR_{rad}, the relative growth rate in normal direction to the cross-sectional plane is necessary, that is in the vertical direction RGR_{vert}; $RGR_{vol} = 2\,RGR_{rad} + RGR_{vert}$. Many authors assume that RGR_{vert} is the same as RGR_{rad} (Richards, 1951: Rees, 1964; Cannel, 1978). This assumption seems to be confirmed for *Triticum* by the studies of Evans and Berg (1971) in which RGR_{vert} was separately determined, it cannot, however, be generalized. An accurate method requires the determination of RGR_{vert} separately from RGR_{rad}.

Studies based on the plastochron ratio in *Lupinus, Dryopteris* (Richards, 1951), *Elaeis* (Rees, 1964), *Picea sitchensis* (Cannel, 1978) and with separate determination of RGR_{vert} in *Chrysanthemum* (Berg, Cutter, 1969) and in *Triticum* (Evans, Berg, 1971) led to the conclusion that the volume relative growth rate of the frusta is constant, i.e. the dimensions increase exponentially with constant relative rate. Particularly noteworthy is the paper concerning wheat on account to the close relationship of the latter to barley. It does not seem probable that there would be such essential differences in the apex growth in these two plants: in barley a considerable slowing down of frustum growth whereas in wheat a constant relative growth rate of the frusta with a very high value (139% per plastochron). Evans and Berg (1971) obtained data on the radial growth rate from the slope of the regression line estimated for the logarithm of radial distance of all 6 primordia present in the germinating embryo. From our own experience we know that the frusta formed before germination start to grow immediately after germination, whereas those newly formed grow much slower. The former increase fast indeed in diametre while the latter do so only in he first plastochron of their existence, and then gradually the growth slows down within the caulis. In Evans and Berg's studies (1971) only 2 frusta formed after germination were present, so they had a relatively small effect on the estimation of the regression line as compared with the older frusta. Thus, it seems that constant high RGR_{vol} for the wheat apex corresponds rather to the rate of growth of the frusta which were already present in the embryo and not to the frusta formed after germination to which our estimates correspond.

Romberger and Gregory (1977) observed in *Picea abies* 136--day-old seedlings that the RGR_{vol} is low in the youngest frustum, but increases attaining maximum at about the 28th frustum. At first RGR_{vert} contributes to the frustum volume growth, but after the initial increase up to the 10th frustum RGR_{vert} decreases to zero at the 37th frustum. A characteristic feature of the caulis in *Picea* is a shoulder which in 136-day-old plants begins with about the 20th frustum. The increase of RGR_{rad} is undoubtedly related to the formation of this shoulder. If the profile of the *Picea* apex were like that in barley and the primordial frustum were of similar size in comparison to the apical dome, the growth rate distribution would be similar in the two kinds of apices. In *Picea abies* the morphology and growth pattern are not quite steady. Thus, the plastochron ratio as well as the ratio of length of successive frusta cannot be used without compensatory procedures in estimating the relative growth rates. Also Smith and Rogan (1975) have shown that in *Agropyron* the plastochron ratio as well as the ratio of length of the successive frusta within the apex change during development, and therefore measurements made on successive frusta at any one stage cannot be used in the calculation of growth rates. The authors found that in newly formed (after germination) frusta the growth rate is initially (during four plastochrons), relatively very low both in radial and vertical direction and then it increases rapidly in radial direction. This initial low growth rate resembles that of the barley apex, however, Smith and Rogan (1975) did not observe a decrease of the relative growth rate in the first plastochron of frustum life. However, the apical dome in *Agropyron* grows at a much faster rate than does the newly formed frustum, thus at least somewhere at the dome basis there must be a rapid decrease of growth rate.

The investigations of Williams (1957) on wheat demonstrated that the relative linear growth rate along the axis within the caulis below the level of leaf primordia initiation decreases with the distance from the tip. This agrees with our conclusion for barley deduced on the basis of the length of the particular parts of the caulis during development.

Determination of the mean growth rate within the apical dome requires data on the changing dome dimensions. The first quantitative studies of this type were performed by Abbe et al. (1951b) on the shoot apex in maize. They found that the mean relative growth rate (per day) of the dome median area increased during 7 plastochrons after germination. Obviously the increase is faster for the RGR_{vol}. When we recalculate the RGR of the dome median surface per plastochron in *Zea*, the rate shows a tendency to oscillate around a constant value. On the other hand, in *Hordeum* there is a trend for constancy of RGR_{vol} per day and for decreasing the rate per plastochron. One possible reason of this difference may be the different proportion of the slow growing distal part of the dome to its fast growing basal part. May be that this proportion is initially higher in *Zea* than in *Hordeum* and that it changes in favour of the fast growing basal part when the dome volume increases. In *Hordeum* the proportion of the slow growing distal part to the fast growing basal one in midplastochron seems to increase in successive plastochrons up to the 8th one. However, our data for comparison of the mitoses distribution just in the midplastochron stage are too scanty to reach any final conclusion.

In *Picea abies* the mean RGR_{vol} for the whole dome is about twice that in the primordial frustum and declines both in the day and the plastochron scale as age increases. Romberger and Gregory (1977) point out that the cause of the decrease in the mean RGR_{vol} for the whole dome may lie in the development of a zone of less active cells in the inner part of the dome. The estimation of the RGR_{vol} indicates that, if "in the 136-day-old dome an active inner zone of half the total volume existed, and the outer zone retained the same activity as the whole 10-day-old dome, then the composite value for the 136-day--old dome would be just as we found it".

The lower relative growth rate of the distal part of the apical dome of shoot meristem seems to be a common feature of seed plants in the vegetative phase of shoot development, although not to such an extent that the distal part could be considered as "meristème d'attente" (see review by Gifford, Corson, 1971; Lyndon, 1976; Rolinson, 1976). The latter author established in rice that cell-doubling times in the dome distal region of 4-day-old plants is 8 times longer than in the dome flanks. The biological meaning of the poor growth of the distal part of the dome seems to consist in a limitation of cell division along the generative line in the vegetative phase, (Hejnowicz, Włoch, 1980).

Though it is commonly believed that in seedlings the rate of leaf initiation remains constant from germination to flower induction (see Berg, Cutter, 1969), the increase in volume of the apical dome on a reinvestment basis and the consequent shortening of plastochron duration observed in *Hordeum* are features found in other species: *Zea* (Abbe et al., 1951b), *Agropyron* (Rogan, Smith, 1974), *Triticum*, *Linum* (Williams, 1975), *Oryza* (Kaufman, 1959), *Silene* (Miller, Lyndon, 1976), *Picea abies* (Gregory, Romberger, 1972a; Romberger, Gregory, 1977), *Picea sitchensis* (Cannel, 1973).

The increase of the apical dome in *Zea* amounts from 31 per cent at plastochrons 7/8 (2nd plastochron after germination), to 8% at plastochrons 13/14 (Abbe, Phinney, 1951a). However the plastochron duration decreases faster than the dimensions of the apical dome increase and the authors stressed this acceleratory character of the relative growth rate in the apex. It is possible, as already mentioned, that the reason for this may be an increasing proportion of cells growing with maximal rate in the dome. In seedlings of *Agropyron* the dome increased from the stage, when the whole lamina of leaf 1 had just emerged from the coleoptile (the apex had then entered the 5th plastochron), during the next 8 plastochrons and then decreased (Rogan, Smith, 1974). However, the relative growth rate in the apical dome of this plant was not studied. In *Picea abies* the investment was about 25% of initial dome volume per plastochron in 10-90-day-old seedlings and decreased rapidly in older apices.

To sum up the results of our own studies and the literature data, the following features of shoot apex growth in seedlings should be stressed which may be of general importance, although in some research methods they may not be brought into prominence:

1. The relative growth rate at the level of the youngest frusta and in the distal part of the apex is lower than in the basal part of the apical dome.

2. The dimensions of the apical dome increase in the initial phase of seedling development on the principle of reinvestment of part of the meristem produced. In connection with this the total production of the apical dome increases.
3. The mean relative growth rate of the volume of the whole apical dome may change, and in this process a change in the proportion of the dimensions of the basal part growing at a maximal rate to the slowly growing distal part may play a role.

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Wzrost i rozwój wierzchołka pędu u jęczmienia. II. Rozmieszczenie szybkości wzrostu w fazie wegetatywnej

Streszczenie

Na podstawie zmian objętości bezlistnej części wierzchołka oraz metamerow merystematycznego pędu stwierdzono, że średnia względna szybkość wzrostu objętości całej bezlistnej części wierzchołka jest znacznie większa niż w pierwszym metamerze, który z kolei rośnie szybciej niż następny metamer. Na podstawie badania rozmieszczenia mitoz oraz układu komórek stwierdzono, że względna szybkość wzrostu objętościowego przyszczytowej części wierzchołka jest co najmniej 5-10 razy mniejsza niż na poziomie inicjowania nowych zawiązków liściowych.