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Phenology and Agriculture

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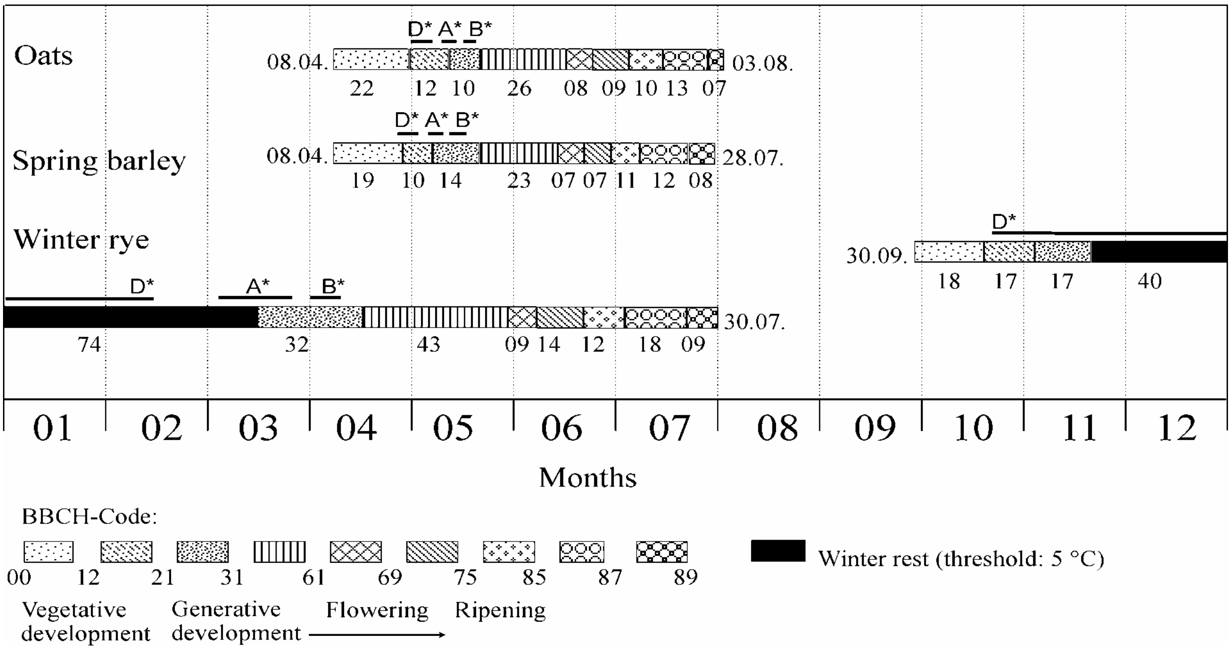

Fig.: Average timing of phenophases and the duration of phenological stages of cereal species between sowing and full ripeness at the Experimental Station Berlin-Dahlem, 1962-1996.

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Phenology and Agriculture

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Abstract

This chapter deals with both traditional aspects of phenology in agriculture (length of growing season and different applications of phenological data in agriculture) as well as modern aspects which focus on impacts of climate change on phenophases of filed crops and fruit trees.

Generally, phenology has a long tradition in agriculture and horticulture. The knowledge of the annual timing of phenophases and their variability can help to improve the crop management which leads finally to higher and more stable crop yields and to an improved food quality. Phenological observations are essential for many aspects in practical agriculture. The data can be used to define the length of growing season in a region. On the basis of the available time in the year, cropping schedules can be developed which include suitable crops and varieties, the organization of crop rotation and catch cropping. Phenological observations also play an important role in the following processes that are relevant in practical agriculture as the timing of irrigation, fertilization and crop protection. The data are also necessary to evaluate the risk of frost damages and to make forecast of plant development and harvest dates. In agrometeorological studies phenological data are used to analyse crop-weather relationships and to describe or model the phytoclimate. The individual sections of this chapter give some examples for the use of phenological data in agriculture and horticulture.

The chapter ends with more recent aspects in plant phenology, showing that the relatively small changes in air temperature have had already distinct impacts on plant development of fruit trees and field crops.

Keywords: Agriculture · Horticulture · Phenology · Climate Change

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1. The Length of Growing Season as an Environmental Limit for Crop Production

The average length of the growing season in a region sets the environmental limits for plant production. Each crop needs a certain time for growth, development, and yield formation. In mid-latitudes the average *growing time* of agricultural crops, which is the time from sowing to ripeness or to harvest, ranges between about 3 and 6 months. Some differences exist among the individual varieties. In regions with a long growing season it is always possible to choose the optimal period for cropping. This means to select the time of the year when the environmental conditions, mainly the climate, is the best for the plant. For crops with a relatively short growing time this is even possible in regions with a limited growing season. Spring cereal such as barley is an early maturing crop and needs a relatively short period from sowing to harvest. For sub-arctic adapted cultivars, the growing time can be less than 80 days. In contrast to this, sugar beets have a relatively long growing time, of more than 6 months (Table 1), which is why sugar beet cropping is limited to regions with a relatively long growing season. The length of growing season also determines how much time is available to cultivate crops in spring or autumn as well as to harvest them at the end of summer. This influences the work sequence and the labor load of farms.

Table 1: Average growing time of selected crops in Germany, Experimental Station Berlin-Dahlem, 1953-2000

Crop	Seeding (day.month)	Harvest (day.month)	Growing time (days)
Winter rye	28.09	01.08	192
Spring barley	04.04	31.07	118
Oats	04.04	06.08	124
Maize	04.05	16.10	165
Potato	26.04	20.09	147
Sugar beet	16.04	24.10	191
Field bean	06.04	15.08	131
Lupine	08.04	23.08	137

1.1 Definitions of growing season

Generally, the growing season is the time of the year in which plants germ, grow, flower, fructify, and ripen. Since most biological processes are bound to water, growth starts above the freezing point, usually at approximately 4 – 5°C for C_3-plants. With increasing temperature the biochemical processes are accelerated (rapidly above 10°C) up to the temperature where enzyme systems are destroyed and cells die (Hörmann and Chmielewski 2001).

There are a lot of ways to define the length of growing season in mid- and higher latitudes. The *climatic growing season* is defined in terms of climatic variables. For instance, thresholds of air temperature can define it, with common values between 0 and 10°C. According to Chmielewski and Köhn (2000), the beginning of growing season was defined as the day of the year on which the average daily air temperature was ≥ 5.0°C (1), with the assumption that on the following days (i) the sum of differences remains positive.

$$\sum_i (T_i - 5°C) > 0°C, \ (i=2,3,\ldots, 30) \qquad (1)$$

Correspondingly, the end of the growing season was defined as the day of the year on which the average daily temperature was < 5.0°C, under the condition that:

$$\sum_i (T_i - 5°C) < 0°C, \ (i=2,3,\ldots, \text{end of year}). \qquad (2)$$

The threshold of 5°C is often used to fix the general growing season for plants in temperate zones. Sometimes for winter cereals a threshold of 3°C is recommended (Reiner et al. 1979).

A similar definition was used by Mitchell and Hulme (2002), who suggested introducing the length of growing season as an indicator of climatic changes. They defined the beginning of growing season as the start of a period when the daily mean air temperature is greater than 5°C for five consecutive days. The period ends on the day prior to the first subsequent period when daily mean air temperature is less than

5°C for five consecutive days. For crops the frost-free season (Goodrich 1984), or the time between the last killing frosts in spring and the first killing frost in autumn (Critchfield 1966; Brown 1976), is also used.

The length of growing season can also be calculated using phenological events. Schnelle (1955, 1961) defined this period as the number of days between sowing of spring cereals and winter wheat. For the beginning of growing season, the timing of phenological events of natural vegetation like bud burst, leafing, and flowering are often used. Accordingly, the end of growing season is then defined by autumn coloring and leaf fall of trees and shrubs.

1.2 The length of growing season in Europe

Using phenological observations of the International Phenological Gardens across Europe (www.agrar.hu-berlin.de/pflanzenbau/agramet/ipg.html) phenological maps of the beginning, end, and length of growing season were calculated (Rötzer and Chmielewski 2001). The beginning of the growing season was represented by the average date of leaf unfolding of *Betula pubescens*, *Prunus avium*, *Sorbus aucuparia*, and *Ribes alpinum.* For the end of growing season, the average dates of leaf fall of *Betula pubescens*, *Prunus avium*, *Salix smithianta*, and *Ribes alpinum* were used. The difference between the end and the beginning of growing season was defined as the length of growing season.

On average, the growing season in Europe starts in most regions between April 10 and April 25. Whereas the British Isles (with the exception of Scotland), Belgium, the Netherlands, the northern part of France as well as Hungary, Croatia, and the former Republic of Yugoslavia show a beginning of growing season between April 5 and 15 (an earlier beginning before April 5 was calculated for southern France, northern Portugal and Spain and for most of the coastal regions of the Mediterranean Sea). A late beginning of the growing season (between April 15 and 25) was found in most parts of Denmark, Germany, the Czech Republic, and Poland. The growing season starts in Scandinavia and in the Baltic Sea region after April 25. In mountainous regions like the Alps or the Dalmatian Mountains, great differences of the beginning of growing season can be seen. While alpine valleys often show a beginning of growing season before April 15, at high altitudes (above about 1500 m) growing season starts nearly 4 weeks later. The latest beginning (after May 30) is observed in the highlands of Norway, and north of the Arctic Circle.

The end of growing season does not have the broad range of annual timings as the beginning of growing season does. While in eastern Europe, most parts of Scandinavia, southern Germany, Switzerland, Austria and the Czech Republic growing season ends between October 25 and 30, the western part of Europe, northern Germany, Hungary, and southern Europe show slightly later dates (between October 30 and November 4). In high altitudes like the Alps, the Carpathian Mountains, the Dalmatian Mountains, or the Scandinavian Mountains the end of growing season can be observed before October 25.

Since the end of growing season shows relatively small variations all over Europe the length of growing season mainly depends on its beginning. The longest growing seasons (with over 220 days) is found in the southern part of France and in the coastal regions of southern Europe (Plate 1). In large parts of Ireland, southern England, the Netherlands, Belgium, most parts of France, Hungary, and in southern Europe (excluding the mountainous regions) growing season lasts between 200 and 220 days (see Table 2). In Scotland and Denmark, in most regions of Germany, in Switzerland, Austria, the Czech Republic, Slovenia, Poland, and in the southern part of Sweden growing season lasts less than 200 days but more than 180 days. Shorter growing seasons with less than 180 days are calculated for high altitudes as well as for nearly entire Scandinavia. High altitudes in Scandinavia as well as the regions north of the polar circle show growing seasons less than 150 days.

Table 2: Average beginning (B), end (E), and length (L) of growing season in different natural regions of Europe, 1969-2000, DOY = day of the year.

Natural Region in Europe	B (DOY)	E (DOY)	L (days)
British Isles/Channel Coast	101	301	200
North Sea / Central European Lowlands	104	302	198
Baltic Sea Region	119	310	191
North Atlantic Mountain Region	127	299	172
North Scandinavia	143	282	139
Northern Central European Highlands	105	305	200
Southern Central European Highlands	108	305	197
North Alpine Foreland	110	303	193
Bav.-Bohemian Highlands / Carpathian Mountains	119	296	177
Great Hungarian Lowlands / Danube-Save-Region	101	303	202
Dinaric Mountain Region / Dalmatia	108	300	192
Portugal	84	-	-

2. Phenological Observations in Agriculture and Horticulture

Phenological observations in agriculture and horticulture are common and have a great value (see section 3). They include such principal growing stages or field works as seeding / planting, germination / bud development, leaf development, formation of side shoots / tillering, stem elongation / rosette growth / shoot development, booting / development of harvestable parts of vegetative plants, inflorescence emergence / heading, flowering, development of fruit, ripening and maturity of fruit and seed, senescence, beginning of dormancy, and harvest.

In Germany, the German Weather Service (DWD) is running a network of about 1,500 phenological observers. The phenological observations cover natural vegetation species, crops, fruits, and vines. Observed crops are sugar beets, permanent grassland, oats, maize, sunflowers, and winter cereals such as barley, rape, rye, and wheat. Observations of fruits include apple, pear, red currant, sour cherry, sweet cherry, and gooseberry species. For vines the varieties Mueller-Turgau and Riesling are observed (see also book chapter 7.5).

In order to have comparable observations it is absolutely necessary to define the phenological phases exactly. For phenological observations, different scales were developed in the past. In agriculture the Feekes-scale was introduced (Feekes 1941). This scale was based on 23 phenological phases for winter wheat between germination and ripeness. By illustrations of Large (1954) the scale became known worldwide (see also Clive-James 1971). In subsequent years the Feekes-scale was modified by many authors for phenological observations of cereals (Keller and Baggiolini 1954; Petr 1966; Broekhuizen and Zadoks 1967). Later, Zadoks et al. (1974) developed a phenological decimal-coded system for cereals, including rice. This scale was published by the European Association for Plant Breeding (EUCARPIA) and is still known as the Eucarpia (EC)-scale. In Germany the EC-scale was adopted by the German Federal Biological Research Centre for Agriculture and Forestry (BBA). In 1981, the BBA also published a decimal code for maize, which was not considered in the EC-scale before. Today the extended BBCH-scale (Strauß et al. 1994) is recommended for phenological observations (see book chapter 4.4). This decimal code, which is divided into principal and secondary growth stages, is based on the well-known cereal code developed by Zadoks et al. (1974).

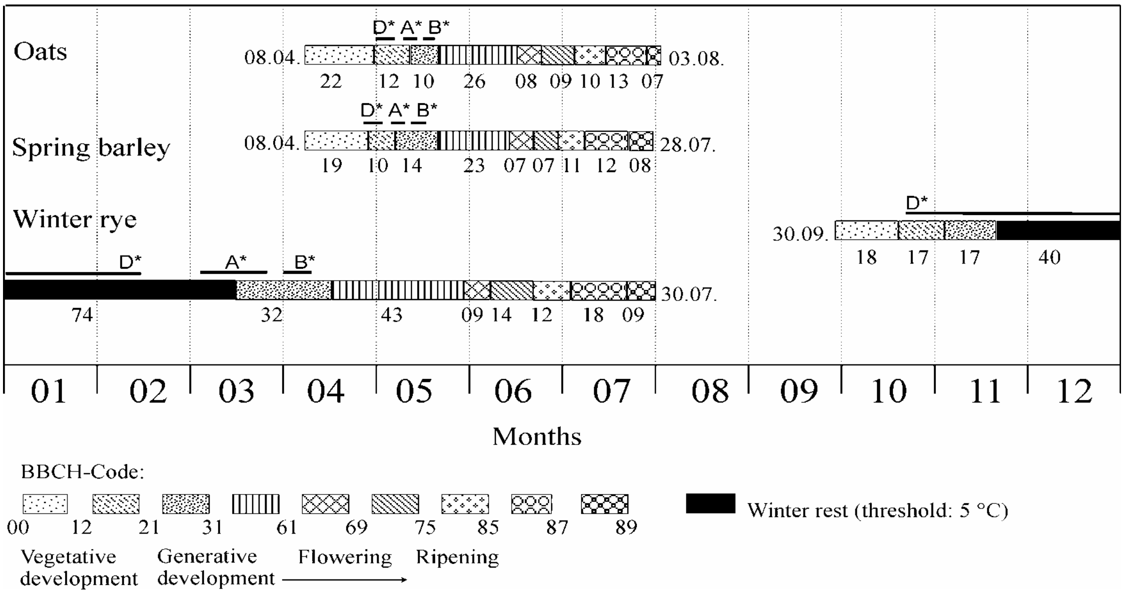

Fig. 1: Average timing of phenophases and the duration of phenological stages of cereal species between sowing and full ripeness at the Experimental Station Berlin-Dahlem, 1962-1996. Phenological stages according to the BBCH-Code: 00: sowing, 12: 2-leaf-stage, 21: beginning of tillering, 31: beginning of stem elongation, 61: beginning of flowering, 69: end of flowering, 75: milky-, 85 dough-, 87: yellow-, 89: full ripeness and micro-phenological tages: D^*: beginning of development at the growth apex, A*: development of spikelets, B*: formation of floret primordial

Figure 1 shows the average timing of selected phenophases for three cereal species (oats, spring barley, and winter rye) at the Experimental Station at Berlin-Dahlem, according to the BBCH-scale. Apart from the phenological macro-stages some micro-phenological stages are also shown which are only visible under the microscope. They describe the development of the growth apex and help to define the beginning of the generative development of cereals. A scale for micro-phenological observations was also developed by Nerson et al. (1980). In Figure 1, the timing of three developmental stages at the growth apex (D^*, A^*, B^*) are shown.

3. Applications of Phenology in Agriculture

Phenological observations in agriculture and horticulture provide basic information for farmers. Knowing the valuable phenological information helps decision-making for farmers, i.e. to correctly time operations such as *planting*, *fertilizing, irrigating*, *crop protection* and to *predict phenophases*. Phenological data are also helpful for scientific applications, such as investigations of crop-weather relationships and to describe the microclimate of crop stands. The following paragraphs give some examples.

3.1 Selection of growing zones

Phenological observations can help to select favourable and unfavourable areas for agricultural and horticultural production. The data can be used for site classifications and to find crops and varieties that grow well under the given climatic conditions. Mainly, fruit and vegetable growing is very sensitive to the site selection. Therefore, phenological observations in horticulture have a great value to define optimal cropping areas, to evaluate the cultivability of fruit trees and vegetable in a given region, and to select individual species and varieties. Poorly adapted varieties show higher yield fluctuations and even yield depressions. For outdoor vegetable growing in mid-latitudes, mainly the warmest areas with an early spring development are recommended. These areas are easily to find with phenological maps. Phenological observations are therefore helpful to sketch regional and local cropping plans. For instance, maps of the beginning of growing season in Germany clearly show the favourable areas for fruit, vine, and vegetable growing. The regions with a very early beginning of growing season are the warmest areas in spring. In these regions, plant development is clearly advanced, compared with the spatial average. Regional studies for the cultivability of crops in Bavaria are represented by Rötzer et al. (1997).

3.2 Crop management and timing of field works

For sustainable crop management, phenological data are essential to meet the right dates for *irrigation*, *fertilizing*, and *crop protection*. For example, maize can grow well in regions where the mean air temperature from May to September is above 15 °C, but in some regions the rainfall is a limiting factor for growth, so that irrigation becomes necessary. The highest water demand for maize is between the beginning of stem elongation and flowering (BBCH 31 - BBCH 69). Irrigation at the right time is a prerequisite for a sufficient grain yield. At the same time, the demand on nutrients is also very high. In just 5 weeks around the period of heading, 75 % of nutrients are taken up. Other cereals as wheat, barley, and rye have similar demands on water and nutrient supply. According to the nutrient requirement, N-fertilization of cereals is recommended at the beginning of the growing season (to promote the process of tillering as well as the formation of spikelets), in the period of stem elongation (to moderate the reduction of tillers and spikelets as well as florets), and if necessary shortly before heading (to encourage the grain size and protein content in the grain).

The application of herbicides for weed control is possible after emergence, for example at BBCH 13 (three-leaf-stage). With the appearance of the last leaf, the flag leaf (BBCH 37), growth regulators can be applied to avoid stalk breakage and the risk of grain lodging. These examples show how phenological information in agriculture are important. Phenological data are prerequisites for adapted and sustainable crop management and to obtain sufficient crop yield. They help farmers to trace the plant development, to monitor the yield formation processes and to find out the optimal time for cultural practices.

3.3 Risk of frost damages

Fruit growers need phenological information mainly in the flowering period and during the ripeness. For these individuals it is important to know the date of latest frosts in a region, especially those that occur after first bloom. Early frosts before the beginning of blossom may cause masked injuries in flower buds, but the damage is not as great as it would be in the period of blossom. Frost during the flowering period can harm the blossoms, so that total crop failures can occur. Phenological observations can help to evaluate the frost risk in a region (see next paragraph). For practical aspects in agriculture and horticulture it is sometimes necessary to estimate the timing of phenological events.

3.4 Forecast of phenological events

Phenological models use different approaches, such as effective temperature sums or chilling and forcing units to predict the timing of phenophases (see book chapter 4.1). In regions were plant development is mainly forced by temperature, there is another simple way to make phenological forecasts using the following equation:

$$P_2 = P_1 + \frac{T_s}{(T - T_B)} \tag{3}$$

where P_2 is the phenophase, which is to estimated, P_1 is the onset of a previous phase, T_S is the effective temperature sum between P_1 and P_2, T is the average anticipated temperature in the period P_1–P_2 and T_B a base temperature of mainly 5°C. For forecasts, it is necessary to make assumptions about the course of temperatures in the forecast period, because temperatures higher than normal lead to advanced plant development and temperatures below normal can delay the developmental process. The best way is to use the data of medium-range weather forecasts. If they are not available it is also possible to estimate the timing of plant development with climatic data. In this case the error is only relatively small if the average temperature in the forecast period is nearly the same as the long-term average. If not, deviations of several days between estimated and observed timing are possible.

Table 3: Statistical measures (x: mean, s: standard deviation) and correlation coefficients (r) between different phenophases (B_G: beginning of growing season, B_C: beginning of cherry trees blossom, B_A: beginning of apple trees blossom, B_{31}: beginning of stem elongation of winter rye (BBCH 31) in Germany, 1961-2000. Correlation coefficient r ≥ 0.31 are significant with p<0.05.

	x	**s**	$\mathbf{B_G}$	$\mathbf{B_{31}}$	$\mathbf{B_C}$	$\mathbf{B_A}$
$\mathbf{B_G}$	109.8	7.3	1.00	0.88	0.92	**0.95**
$\mathbf{B_{31}}$	116.6	6.1		1.00	**0.91**	0.88
$\mathbf{B_C}$	116.9	7.5			1.00	**0.96**
$\mathbf{B_A}$	125.3	7.4				1.00

There are also ways to estimate phenological events without any information about the temperature values in future days, since phenological events are usually well correlated with each other. There is on the one hand a good correlation between phenophases of different species in the same time of the year (Table 3), and on the other hand good correlations in the successive plant development of one species (see later Table 4). For instance, a good indicator for the beginning of field works in mid-latitudes (the first cutting time of meadows) is the anthesis of winter rye. About one week after anthesis the meadows can usually be cut.

The beginning of growing season in Germany is well correlated with the blossom of cherry ($r=0.92$, $p<0.01$) and the blossom of apple trees ($r=0.95$, $p<0.05$). So, it is possible to predict the average blossom of fruit trees with this event. The stem elongation of winter rye and the blossom of cherry trees start nearly at the same time in the year (Figure 2). This phenophase can be used to investigate the probability for killing frosts after the beginning of blossom, and to evaluate the planting risk of fruit trees in a region. Phenological observations of fruit trees are not always necessary to do this.

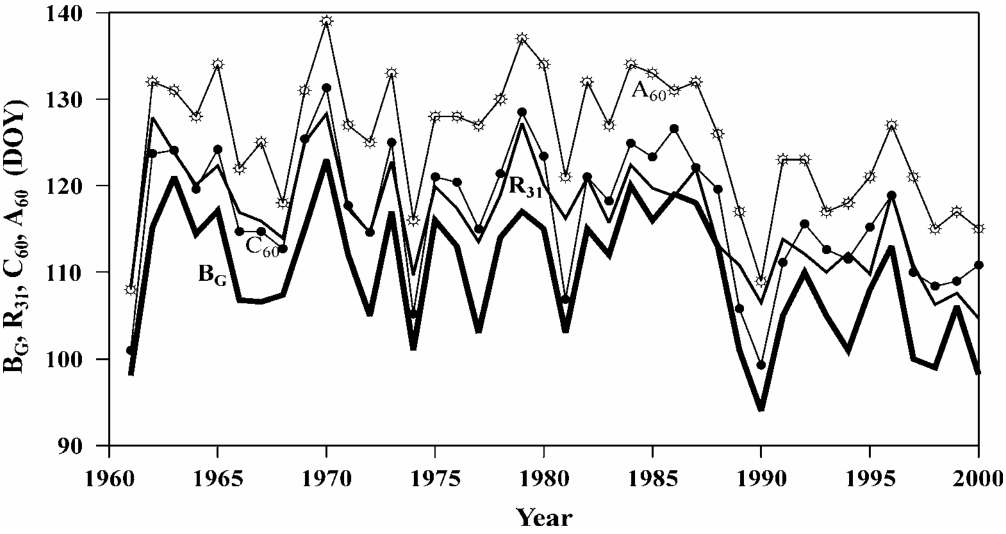

Fig. 2: Beginning of growing season (B_G) and the beginning of blossom of cherry trees (B_C), apple trees (B_A), and beginning of stem elongation of winter rye (B_{31}) in Germany, 1961-2000. Data: German Weather Service (DWD).

The good correlation between the phenological stages of one species gives another possibility to predict phenological events (Table 4). For this method the phenological observations should be done very detailed. The timing of a phenological phase (P_2) can be estimated using the previous phase (P_1):

$$P_2 = a + b\,P_1 \tag{4}$$

Larger deviations in the plant development from the long-term average are reduced gradually, so that successive phenological stages are usually positively correlated. There is always a minimum period between two successive phases. Table 4 shows that for winter rye it is possible to estimate the beginning of heading using the beginning of shooting ($r=0.93$). Also the timing of emergence and full flowering can be estimated by the previous phase. With increasing time period, the correlation between the phenological events decreases, so that it is not possible to estimate a phenological event by a very early one. Relatively good results can always be achieved if the previous phase is taken.

Table 4: Correlation coefficients between different phenophases of winter rye in Germany, 1961-2000, (BBCH-Code is used, 00: seeding, 09: emergence, 31: beginning of stem elongation, 51: beginning of heading, 65: full flowering). Correlation coefficient $r \geq 0.31$ are significant with $p<0.05$.

BBCH	00	09	31	51	65	Harvest
00	1.00	**0.97**	0.52	0.45	0.31	0.20
09		1.00	**0.53**	0.46	0.31	0.18
31			1.00	**0.93**	0.69	0.53
51				1.00	**0.85**	0.64
65					1.00	**0.66**
Harvest						1.00

3.5 Crop-weather relationships

Crop yields are influenced by the variability of weather in many ways. For cereals the yield formation is very complex. Phenological observations can help to divide the growing time of crops into different periods that are important for the yield formation (Table 5). So, it is possible to find out relationships between weather and crop yield for different periods in which the individual yield component is affected.
Investigations by Chmielewski and Köhn (1999) showed that for spring barley in the first period mainly the number of kernels per ear, in the second period the crop density, and in the last period the kernel weight are influenced by weather. For winter rye, it was also possible to find out the relevant phenological periods with regard to the yield formation (Chmielewski and Köhn 2000). Thus, phenological observations are absolutely necessary to describe the yield formation of crops more in detail. Crop models use phenological information as well, to steer physiological processes in the model. Therefore, phenological models are always subroutines of mechanistic crop models (see book chapter 4.1).

Table 5: Relevant developmental periods for the yield formation of spring cereals. The dates are given for spring barley at the Experimental Station in Berlin-Dahlem, 1962-1996

Period	Yield Forming Processes
2-leaf-stage (BBCH 12) – Beginning of stem elongation (BBCH 31) 27 April – 21 May	- formation of side-shoots - tillering Beginning of development at the growth apex: - formation of spikelets (D*: 26.04 – 03.05.) - differentiation of spikes (A*: 06.05 – 10.05.) - formation of florets (B*: 12.05. – 17.05.)
Beginning of stem elongation (BBCH 31) – General flowering (BBCH 65) 21 May – 16 June	- reduction of tillers and spikelets - differentiation and reduction of florets - flowering
General flowering (BBCH 65) – Yellow ripeness (BBCH 87) 16 June – 20 July	- formation of kernels - growth and ripeness of kernels

3.6 Microclimate of crop stands

Crop stands have their own climate that can differ tremendously from the climatic conditions at a meteorological station. The microclimate of crop stands (phytoclimate) depend on various meteorological (solar radiation, air temperature, precipitation, wind speed) and plant-morphological factors (structure of plant cover, plant height, density of stand, etc.) and thus also on the plant development. Therefore, phenological observations are essential to analyse and to understand the microclimate of crop stands.

During the day the air within a crop stand is warmer and wetter than the air above a bare soil (Wittchen 2002). The phytoclimate varies during the daytime and with the growth and development of the crop stand (Figure 3). The largest air temperatures differences occur in the last developmental period (P4) at noon. Then the winter rye stand in 0.20 m height is significantly warmer, compared with the air above a bare soil at the same level. During the flowering phase (Phase 3) the differences in water vapor are the largest. They are already reduced in the grain filling and ripeness period, because then the stand becomes dryer and dryer.

These specific phytoclimatic conditions have effects on the phytopathological situation within the crop stand, because the development of fungi and insects is determined by given temperatures and humidity levels, typical of each species. In the case of insects, the air temperature in the breeding places of insects is important for the eggs to hatch and for the larvae to be able to perform their various transformations (see book chapter 6.2).

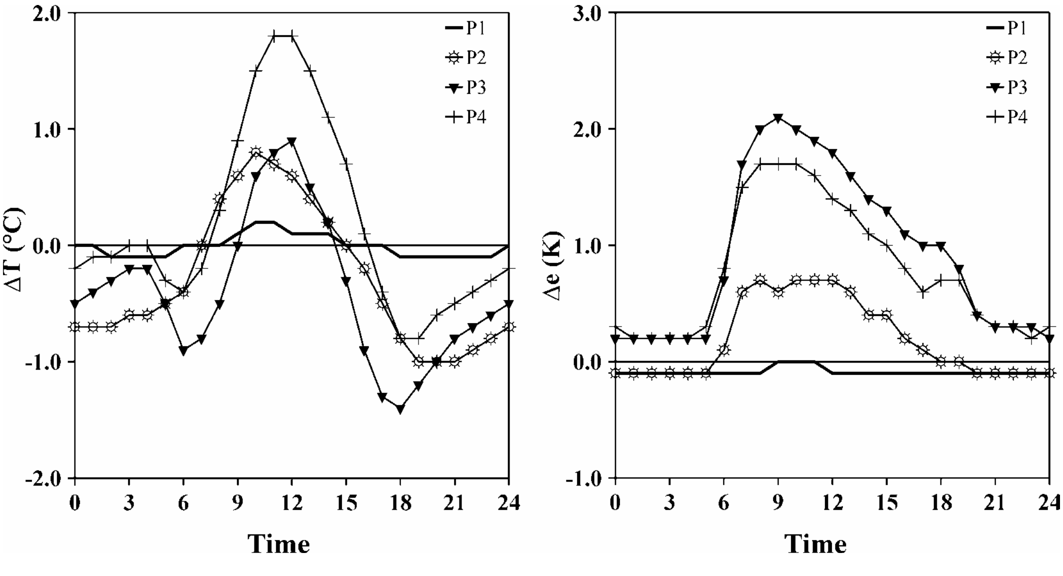

Fig. 3: Average anomalies in air temperature (ΔT) and in water vapour pressure (Δe) between a winter rye stand and a bare surface in 0.2 m height during different developmental periods. P1: leaf development and tillering period (BBCH 10-29), P2: stem elongation and heading period (BBCH 30-49), P3: flowering period (BBCH 50-69), P4: grain filling and ripeness period (BBCH 70-89), at the Experimental station in Berlin-Dahlem, 1981-1999 (positive anomalies mean the stand is warmer and more wet).

For fungi, beside air temperature mainly the air moisture or the water on plant organs plays important roles. Since the phytoclimate depends on the plant development, the infection risk also changes with plant development. For example for winter rye the

infestation frequency is very high in the last two phases (P3, P4), because of the higher air humidity in these two periods - compared with the climatic conditions outside the stand. As a measure for the infection risk in phytopatological models often the relative humidity is used. Here mainly the time periods with values of at least 75% are relevant.
Investigations by Wittchen (2002) showed that for time intervals of more than 12 hours the relative humidity in Phase 3 and Phase 4 is indeed significantly higher compared with the conditions in a weather shelter (Table 6). On the other side in Phase 4 the air temperatures mostly exceed the optimal range for infections, so that the infection risk in the winter rye stand is the highest during the flowering period.

Table 6: Relative frequency of relative humidity $H_R \geq 75$ % within a winter rye stand, compared with H_R in a weather shelter (2m height).

	Duration of $H_R \geq 75$ % for different time intervals in %					
Time interval (h)	1 … 6	7 … 12	13 … 18	19 … 24	25 … 36	> 36
			Flowering period (P3)			
Stand	15.3	32.3	**33.5**	**8.2**	**1.6**	**9.1**
Shelter	**37.6**	**38.1**	14.6	4.9	1.3	3.5
			Grain filling and ripeness period (P4)			
Stand	17.7	34.8	**33.4**	**8.8**	**1.0**	**4.3**
Shelter	**31.6**	**41.4**	19.8	3.8	0.9	2.5

4. Climate Changes and Phenophases

The strong relationships between air temperature and plant development in mid- and high-latitudes make phenological observations sensitive indicators to evaluate possible biological impacts of climate change. Since the end of the 1980s, clear changes in air temperature have been observed in Europe and also in Germany. Mainly the temperatures in winter and in the early spring - which are decisive for the plant development in spring - changed distinctly. Most recent years were warmer than the long-term average (Chmielewski and Rötzer 2002). These observed changes in temperature correspond well to changes in the circulation pattern over Europe. The increased frequency of positive phases in the North Atlantic Oscillation index (NAO) since 1989 led to milder temperatures in winter and the early spring, because of the prevailing westerly winds from the Atlantic Ocean during this time of the year (Chmielewski and Rötzer 2001).
These climate changes led to distinct reactions in the flora. Between 1969 and 2000, the average beginning of growing season in Europe has advanced by 9 days. This corresponds to a significant trend of -2.8 days/decade ($p<0.05$, Figure 4). In accordance with the climatic changes, mainly since the end of the 1980s, early dates prevail. Between 1989 and 2000, 10 out of 12 years had an advanced onset of spring. Compared to the beginning of growing season, the average end of growing season shows smaller annual variations. The trend to a later end of about 1 day/decade is relatively small. Mainly influenced by the earlier beginning, the average length of growing season had advanced by 11 days, corresponding to a significant trend of 3.5

days/decade (p<0.01). Because of the very early onset in 1990, this year had the longest growing season (200 days).

Changes in the length of growing season can influence crop management in agriculture and horticulture such as *cultivar selection*, *catch cropping* and *crop rotation*. Small changes in the length of growing season can already influence the *choice of varieties*. Fast ripening varieties can be replaced by slower ripening ones, if the growing season extends. This measure could have positive effects on the yield variability and on the yield level. In fruit growing changes of the varieties are also possible, because the differences in the growing time of fruit varieties are mostly only several days.

Catch cropping depends on the time available after harvest in the late summer or early autumn, before another crop is cultivated. Thus, catch cropping is only possible in regions where the growing season in autumn is long enough and the air temperatures and precipitation are still favourable for plant growing. For example an advanced harvest date of spring cereals would improve the conditions for catch cropping, so that it is possible to grow legumes, before winter cereal is sown. More distinct changes in growing season length by several weeks can influence the possibilities for catch cropping and for crop rotation.

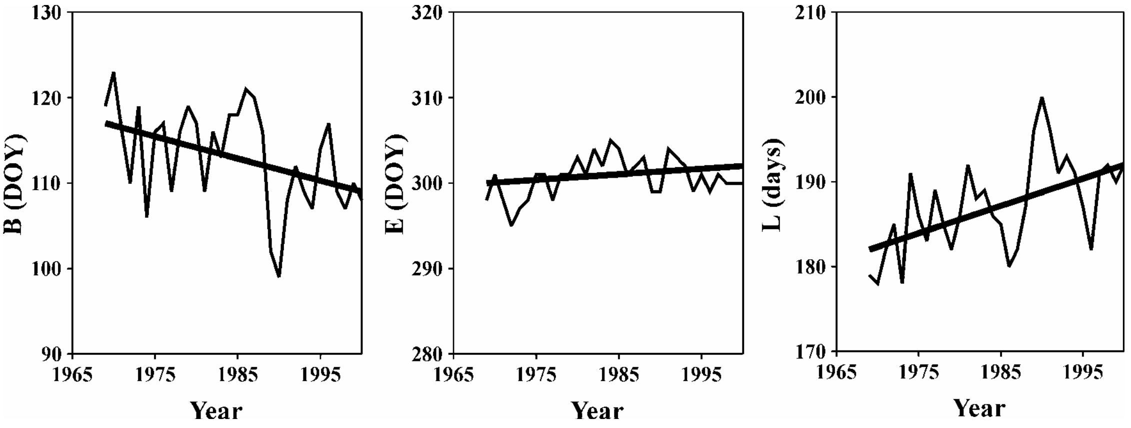

Fig. 4: Trends in the beginning (B), end (E) and length (L) of growing season in Europe, 1969-2000 on the base of observations of the International Phenological Gardens.

Crop rotation is a system in which the crops on a certain plot are followed by other crops according to a predefined plan. Normally the crops are changed annually, but in some areas where the growing season is sufficiently long, multiple cropping is possible. An extension in the length of growing season can improve the scope for multiple cropping and crop rotation. For example, if the end of growing season is extended the sowing time of winter cereals can be shifted to the end of the year, so that in the space before crops with a relatively long growing time (as sugar beets) can grow. In the field, vegetable growing multiple cropping is common. Here also an extension of growing season can improve the crop rotation and number of harvests within a year.

But not only the length of growing season has changed in recent years. Events, such as the first bloom of fruit trees in Germany (apple, cherry, etc.) were also influenced by higher temperatures during the end of winter and in early spring (Chmielewski et al. 2003). An increase of average air temperature between February and April of 1.6 degree Celsius between 1961 and 2000 led to an advanced tree blossom in Germany of 8 days (Figure 5). Here also the most distinct changes occur since 1989.

An earlier blossom of fruit trees holds at the same time the danger of damages by late frosts. Thus it is very important to monitor the changes in plant development, to be prepared for the impacts of climatic changes on agriculture and horticulture.

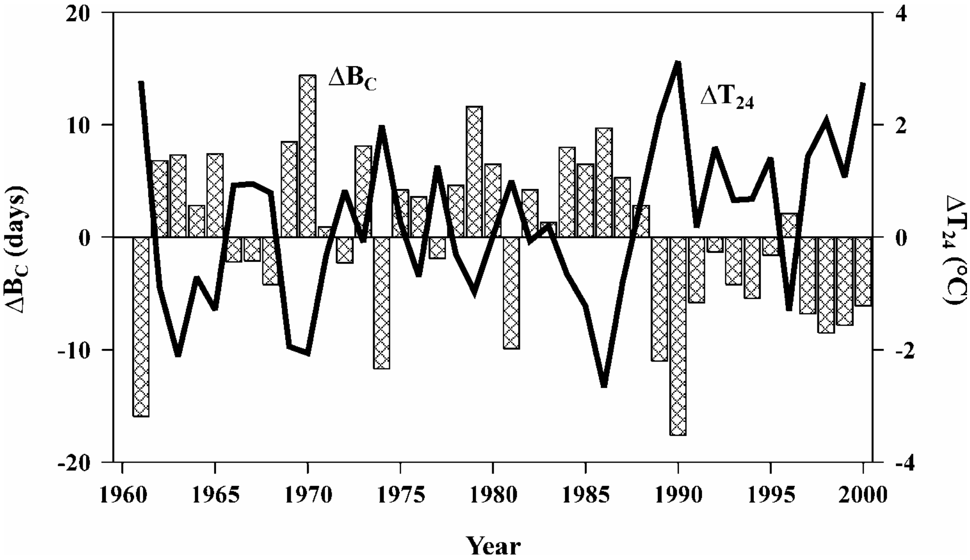

Fig. 5: Anomalies in the first bloom of cherry trees (B_C) and in the average air temperature from February to April (T_{24}) in Germany, 1961-2000. Data: German Weather Service (DWD).

Phenological research can improve the selection of fruit varieties for specific regions to reduce the risk of potential frost damage. It can result in better projections and assessments of flowering times and occurrence of pests and diseases. This will improve and substantially reduce the use of pesticides and increase the agricultural production potential in Europe. Information on the potential effects of climate change on agricultural and horticultural crops by changes in phenology are still limited at this time.

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