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Review article

IMPORTANCE OF PHENOLOGICAL OBSERVATIONS AND PREDICTIONS IN AGRICULTURE

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Abstract: Phenology can contribute to many scientific disciplines from climate change, biodiversity, agriculture and forestry to human health. The knowledge of timing of phenological events and their variability can provide valuable data for planning, organizing and timely execution of certain standard and special (preventive and protective) agricultural activities that require advanced information on the dates of specific stages of crop development. Mathematical models are the basic tools to predict the timing of phenological events. There are two types of phenological models: physiologically-based and statistical. Most of the existing models are statistical and serve to predict the onset of different phenophases according to the air temperature. These models are site- and species-specific and cannot be applied to a wide range of species and climatic conditions.

Key words: phenology in agriculture, phenology data, phenology models.

Introduction

Phenology is the study of the timing of recurring biological events, the causes of their timing with regard to biotic and abiotic forces, and interrelation between phases of the same or different species (Leith, 1974).

Recently, there has been a significantly increased interest in phenology primarily due to shifts in the timing of different phenological phases in plants, insects, birds and amphibians connected to climate change (Crick et al., 1997; Menzel and Fabian, 1999; Sparks et al., 2000; Penuelas et al., 2002). Phenology variables are indicated as some of the most sensitive data to climate conditions, and therefore were proposed by the European Environmental Agency as climate difference and global change indicators (Menzel, 2003).

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Most of the papers report changes in the phenology of natural vegetation, but some researchers investigated trends of agricultural varieties (Chimielewski et al., 2004).

Besides climate change studies, phenology can contribute to many scientific disciplines from biodiversity, agriculture and forestry to human health. It provides valuable data for land-use planning and crop zonation, control of agricultural, forestry and domestic pest species, protection of species of conservation interest, and information on pollen release and its implications for human health.

Phenology has a long tradition in agriculture and it can be said that historical interest in the phenology has come from an interest in plant development and growth and their relation to climate. The knowledge of timing of phenological events and their variability can help to get more stable crop yields and quality through improved and sustainable crop management providing dates for timely irrigation, fertilizing, and crop protection.

Phenological dynamics is determined by complex interactions between genetic and environmental factors. Among the plant phenological phases, the flowering time is the most often considered, because it is one of the simplest to record and one of the easiest to interpret. Researchers have found air temperature to be a dominant factor controlling the timing of flowering and other phenological phases (Hunter and Lechowitz, 1992; Galan et al., 2001; Vulić and Ruml, 2002; Ruml and Vulić, 2004). However, temperature cannot explain all the variation in plants development related to their environment. Some researchers stress the importance of photoperiod, as well as rainfall and solar radiation (Friedel et al., 1993, Vulić and Ruml, 2001). Although the influence of soil on plant development is usually smaller than the influence of climate (Weilgolaski, 2001), sometimes the impact of soil temperature, water content, soil type and nutrient supply could be significant (Wielogalski, 1999).

Phenology data

Phenological stages must be defined exactly in order to have comparable observations. There is a difference between phenological stage and phenological phase. Phenological stage is a single point during development, such as full bloom, while phenological phase is the time between two stages, such as grain filling of wheat. Data from a single location can be valuable if they exist for a long run of years (usually more than 20 years).

Republic Hydrometeorological Service of Serbia is running a phenological stations network in Serbia. The phenological observations in former Yugoslavia started in 1951 (Federal Hydrometeorlogical Service of SFRJ, 1963), much later than in some other parts in the world (i.e. UK records are going back to the 1730, Sparks and Carey, 1995). The monitoring program covers: natural vegetation species, crops, fruits, vines, plant diseases and pets, birds, bees, general field works and nonorganic phenomena (date of first snow, floods, etc).

The observed crops are: winter wheat (*Triricum sativum*), winter barley (*Hordeum sativum*), winter rye (*Secale cereale*), winter oats (*Avena sativa*), spring barley (*Hordeum sativum*), spring oats (*Avena sativa*), rice (*Oryza sativi*), maize (*Zea mays*), potato (*Solanum tiberosum*), sugar beet (*Betula vulgaris saccharifera*), beetroot (*Beta vulgaris crassa*), sunflower (*Heliantus annuus*), tobacco (*Nicotiana tabacum*), hemp (*Canabis sativa*), cotton (*Gossipium herbaceum*), flax (*Linum usitatissimum*), poppy (*Papaver somniferum*) and hops (*Humulus lupulus*). The observed fruits are: apple (*Pirus malus*), pear (*Pirus communls*), plum (*Prunus domestica*), cherry (*Prunus svium*), sour cherry (*Prunus cerasus*), apricot (*Prunus armeniaca)*, peach (*Prunus persica*), almond (*Amygdalus communis*), red currunt (*Ribes rubum*), olive (*Olea europaea*), fig (*Ficus carica*), lemon (*Citrus limonium*), orange (*Citrus aurantium*) and vines (*Vitis vinifera*).

Among 142 stations in Serbia, where phenological observations were performed for more than 5 years in the period from 1951 to 2002, 85 stations have observation series longer than 20 years. These data are often “noisy” due to many factors as for example skill and effort of the observer. Noise element is reduced when data are averaged across sites. Historical phenological data often exist in a paper form, not in the format suitable for scientific work. Formation of computer archive of historical data would be necessary.

Phenological models and methods

Mathematical models are the basic tools to predict the timing of phenological events. There are two main approaches in designing these models. One is physiologically based and takes into account cause-effect relations between biological processes (i.e. accumulation of grow-promoting and grow-inhibiting compounds) and driving external forces, most often climatic (Hanninen, 1994). Another approach is statistical, which uses correlations between phenophases onset of different species (Linkosalo, 2000) or correlations between selected phenophases and meteorological variables (Cenci and Ceschia, 2000). Observed data are used to obtain model parameters using various fitting methods, more or less complex.

Most of the existing models are designed to predict onset of different phenophases according to the air temperature (Kramer, 1994; Synder et al., 1999; Wielogalski, 1999). Some of them consider only the heat requirements, while others take into account chilling requirements, too.

During the winter, the activity of orchard and deciduous forest species is reduced. Although, the term dormancy is in the way self-explaining, there are various definitions of it. According to Lang et al. (1987), dormancy is a state of reduced or stopped activity or development of specific plant tissues that will resume in the future. Many authors divide dormancy into two periods: rest period and quiescence (Sarvas, 1974; Hanninen, 1990; Linkosalo, 2000); Vulić et al. (2004) termed rest period as biological dormancy, since it is due to physiological conditions of plants, and quiescence as ecological dormancy, since it is due to environmental conditions.

The period of dormancy is usually determined by the number of chilling hours or chilling units. Chilling requirement can be calculated simply by accumulation of hours below a temperature threshold (chilling hours) or taking into account the fact that temperature's effectiveness diminishes, when it departs from the optimum value (chilling units). The weighting factors for chill unit models are mainly determined by laboratory tests. The conventional start date for chilling accumulation is 1 October.

Some of the most used "classical" models for predicting bud burst of fruit trees are: "Utah" model (Richardson et al., 1974), the "North Carolina" model (Shaultout and Unrath, 1983), the "Low Chilling" model (Gilreath and Buchanan, 1981), and the "Positive Chill Unit" model (Linsley–Noakes et al., 1995). These models predict release of dormancy only as a result of chill accumulation.

Some more sophisticated models take into account the processes of breaking rest in terms of chill accumulation and overcoming quiescence by accumulating forcing anti–chill temperatures. In so-called sequential models (Cannel and Smith, 1983; Fuchigami and Nee, 1987; Cesaraccio et al., 2004), heat accumulation starts after the chilling requirement has been satisfied, while in so-called parallel models (Hanninen, 1994; Kramer 1994; Shaber and Badek, 2003), dormancy release occurs in response to forcing temperature, even when the critical cold temperature accumulation is not achieved (chill and heat accumulation overlap).

Hunter and Lechowitz (1992) compared the accuracy of different phenological models in predicting bud-burst of native tree species. They found out that the most physiologically correct models are not necessarily the most accurate ones.

Further development, after release of dormancy, is usually measured as heat accumulation above threshold temperatures, calculated as degree-days or degree-hours. The heat accumulation starts after satisfaction of chilling requirement or after some fixed date, most often after 1 January in the middle latitudes.

Threshold temperature defined in physiological sense as a certain temperature below which plant development ceases, vary with several factors related both to the plant and the environment (Synder et al., 1999; Chuine and Cour, 1999; Wiegolasky, 1999). In most models, the threshold temperature is determined statistically rather than physiologically. Most commonly used fitting methods to determine the best threshold temperatures from field observation are: (i) the least standard deviation in growing degree-days (Magoon and

Culpepper, 1932); (ii) the least standard deviation in days (Arnold, 1959); (iii) the coefficient of variation in days (Nuttonson, 1958); (iv) the regression coefficient (Hoover, 1955).

The estimated threshold temperatures vary considerably with methods used. The same applies to the value and length of heat and chilling requirement. This makes difficult to compare and use values of threshold temperatures and temperature sums given by different authors.

Models have several practical uses in agriculture, since some agricultural activities require advanced information of certain stages of crop development. Output results from phenological models in agriculture can be used to:

- determine timing of sowing, pruning, pesticide use, irrigation, frost protection;
- predict maturity dates, yield and quality of crops, which improves the market delivery;
- determine the limits of geographical areas suitable for production of various crops, specially new and non-native;
- select the crop varieties for specific region to minimize the risk of frost damage, and
- estimate the magnitude of ongoing and expected shifts in phenophases occurrence due to global warming.

Discussion and Conclusion

In middle latitudes, with vegetation rest period in the winter and active growing period in the spring-summer time, phenology dynamics of plants is mainly driven by temperature (Chmielewski and Rötzer, 2002).

Despite the desirability of using physiologically based-models and certain limitation of temperature-based models (Ružić et al., 2004), they are still the basic tool in phenological studies, because the nature of different developing stages and their physiological and morphological status is not yet fully understood (Shaber and Badek, 2003). Fortunately, in some cases these models perform quite well and meet different specific needs. However, it must be emphasized that they are site- and species-specific and cannot be applied to a wide range of species and climatic conditions.

Observed shifts in the timing of phenological events are still moderate - up to few days per decade (Scheifinger et al., 2003; Feng and Hu, 2004). The expected climate changes in 21st century will be most likely larger than those observed in the last century (Houghton et al., 20001). Substantial effects on crop potential are expected at higher latitudes, because future temperature increases are expected to be greater at these latitudes, and because agricultural potential decreases poleward, while sensitivity to temperature rises. Climate changes will affect crop potential through changes in the length of growing season, crop yield, and spatial shift in agriculture potential.

Most of the fruit trees and even annual crops investigated in different studies showed advanced beginning of spring phenological phases with increased air temperature in most parts of northern hemisphere. However, this might not always be the case, since the longer period of dormancy due to mild winters, can delay onset of spring phenophases. Advanced beginning of vegetation with slightly smaller delay of the end of vegetation will lead to extension of the growing season (Chimielewski and Rötzer, 2001). The prolongation of the growing season will have mostly positive effects on crop farming, improving the scope for cultivar selection, catch cropping, crop rotation and number of harvests per year (Chimielewski et al., 2004). Yields of most crops in cool-temperate and cold region is expected to increase with increasing temperature (i.e. northern part of Europe), except in regions where moisture is a limiting factor. Temperature rise in combination with other factors could lead to a significant shift of agriculture resources. Several studies predict that a 1°C increase in mean annual temperature would tend to advance the thermal limit of cereal cropping in mid-latitude regions by about 150-200 km, and raise the altitudinal limit by about 150-200 m (Ruml, 2003).

On the other hand, the earlier beginning of vegetation could increase the risk of late spring frosts, which in combination with milder winter could pose a threat for even a frost resistant species (Burroughs, 2002). However, this might not happen, since we can expect higher minimum temperatures in spring and shift of late frost dates to earlier occurrence. Scheifinger et al., 2003 showed that frost events in Central Europe had been moving faster to earlier occurrence than onset of phenological phases during the last decades in Central Europe, so the risk of late frost damage has been lowered in this part of the world.

Therefore, there is a need for further research to be done, using more reliable phenological data and models developed for larger geographical areas rather than for single location, in order to improve understanding of interaction between climate and natural systems, estimate possible climate-induced ecological changes, and find the best adaptation and mitigation strategies in agriculture, forestry and all other aspects of human life.

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ZNAČAJ FENOLOŠKIH OSMATRANJA I PROGNOZIRANJA U POLJOPRIVREDI

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Rezime

Fenološka osmatranja imaju značaj za mnoge naučne oblasti, naročito za klimatologiju, biologiju, medicinu i biotehniku. Sistematska fenološka osmatranja u Srbiji započela su 1951. godine, znatno kasnije nego u nekim drugim delovima sveta.

Uprkos nedostacima statističkih modela prognoziranja fenološke dinamike, oni u određenim slučajevima daju zadovoljavajuće rezultate i nalaze različite primene. Ukoliko se selektivno primene na određenu vrstu u određenim klimatskim uslovima, mogu pružiti vredne informacije: za planiranje i pravovremeno izvođenje agrotehničkih i fitotehničkih mera i postupaka; za predviđanje vremena sazrevanja plodova, njihovog kvaliteta i visine prinosa; za rejonizaciju gajenja pojedinih novostvorenih i introdukovanih sorti; za selekciju sorti u cilju minimiziranja nepovoljnog dejstva stresnih faktora (posebno mraza); za procenu posledica globalnih i regionalnih klimatskih promena po poljoprivrednu proizvodnju i sl.

Izrada modela za fenološke prognoze koji bi važili za šire geografske oblasti omogućilo bi osmišljavanje strategije ublažavanja i otklanjanja štetnih posledica vremenskih i klimatskih kolebanja, što bi značajno unapredilo rezultate ne samo biljne proizvodnje, već i neke druge aspekte ljudske egzistencije.

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