Wheat Crop Phenology for Advisors

Definition of phenology

Modern phenology is the study of the timing of recurring biological events in the animal and plant world, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species. (Guidelines for plant phonological observations, Foundation for Sustainable Development, Netherlands)

Wheat

Wheat has proven itself to be a highly adapted crop across the world, being successfully grown from the tropics to close to the Arctic Circle. However one variety itself does not possess the ability to survive in this range of environments. The crop achieves this by the interaction between the genetics and the environment to produce an adapted variety. The key environmental influences are temperature and photoperiod and these determine the lifecycle of the crop so as to provide the best fit to the environment.

Overview of Crop Development

The wheat plant goes through a series of developmental phases from sowing to harvest. There are several systems for describing the developmental stages the crop progresses through. The principal system used by Australian agronomists is the Decimal Code for the Growth Stages of Cereals developed by the Dutch phytopathologist, Jan C Zadoks (see appendix 1 for a full description (http://www.croppro.com.au/cb_pages/decimal_code_for_the_growth_stages_of_cereals.php)). While the numbering of the stages remains consistent, the preceding letters can be either DC (Decimal Code and technically correct), GS (Growth Stage) or Z (Zadoks) and this identifies the code proposed by Zadoks. Other developmental systems have been developed, e.g. Feekes, but are not widely used in Australia.

Sowing the crop – DC 0

After sowing, the seed adsorbs moisture and the various biochemical processes begin, resulting in the production of the first root and shoot. Both the first root and shoot are protected by a sheath called the coleorhiza (root) and the coleoptile (shoot). Coleoptile length varies between varieties, and herbicides such as trifluralin and some seed dressings can reduce the length of the coleoptile. If the coleoptile terminates below the soil surface, the first leaf is far less effective in pushing through the soil and may not emerge. Once the coleoptile reached the surface, the first leaf appears through a pore at the tip.

At this stage, all the energy required for the first leaf to emerge is provided by the seed reserves. Deep sowing or any other factor that requires the plant to expend more energy getting the first leaf through to the surface, apart from delaying emergence, results in weaker and smaller seedlings that may be more prone to weed and pest competition.

At germination, the meristem or growing point of the plant in the embryo already contains 3 leaves. Leaf production continues at a faster rate than leaf emergence, and the number of leaves produced varies from 5 to 20 depending on the variety. Leaf emergence is controlled by the temperature, which will be discussed in a later section.

Vegetative phase – DC 1 to DC 2

The first leaf to emerge, which can be identified by a rounded tip, is soon followed by the second and then a third at a rate dependent on temperature. Leaf production is followed by tillering. Tillering is the production of new shoots from buds at the leaf base. The process mimics emergence in that the developing shoot is protected in a modified leaf called the prophyll which performs a similar function to that of the coleoptile in protecting the young shoot. Tillers are formed in sequence, with the first potentially developing when the plant has 2.5 to 3 leaves emerged (Figure 1 below). Tiller production occurs at a similar rate as leaf emergence, and so the next tiller may emerge at the 3.5 to 4 leaf stage and so on. There is a small timeframe for the tiller bud to be activated by the plant and if this timeframe is affected by environmental stresses such as drought or nutrition, then the tiller may not develop.

Aside from moisture, the nitrogen status of the soil influences either tiller development or death. As stated above, low levels of soil nitrogen can result in the tiller missing its cue to develop (Picture Two below). In areas with low rainfall/yield potential, this may be acceptable. But if establishment has been poor, or the crop intended for grazing, then encouraging as many tillers as possible could be promoted with nitrogen application. Conversely, excessive amounts of nitrogen at this stage of development can promote excessive tillering and larger leaves, all which increase the use of soil moisture. If the crop is in an environment that is likely to see moisture stress later in the season, this can represent wasted moisture and nitrogen and increase the risk of the crop “haying off”.

Tiller then effectively acts as a new plant, with the potential for another shoot to develop once that tiller reaches the 2.5 to 3 leaf stage.

Overall tiller production is controlled by both the environment and genetic factors, with some varieties genetically predisposed to low tiller numbers. Tiller production stops approximately at the same time as stem elongation commences.

While the shoots continue to develop, a similar process is happening with the root system. From germination, the first roots to develop are referred to as the seminal roots. These are relatively fine and fibrous.

The secondary root system to develop is the nodal roots. These roots tend to be thicker than the seminal roots. They start to appear at the 3 leaf stage. These are important roots for not only sourcing moisture and nutrients, but also help anchor the plant. Roots are produced in a sequence similar to leaf and tiller emergence. Once again, the development of these roots can be impacted upon by environmental stresses. This is important for crops sown for grazing as the plants must be firmly anchored in the soil to resist being pulled out when grazed.

Reproductive phase – DC 3 - 6

While leaves are still emerging from the plant crown, the growing point of the plant has already changed from the vegetative phase (producing leaves) to the reproductive phase (producing the head). Depending on the variety, the change may be genetically programmed in after the production of a certain number of leaves or in response to cues from the environment such as day length or a period of cold temperature. Often the varieties are categorised as “spring types” or the traditional varieties that are sown in the north of the dividing range where the change to the reproductive phase has either minimal influence from the environment or may have the change delayed to some degree in response to day length. In early season cultivars, this may occur approximately 6-8 weeks after emergence. The “winter” types, also referred to as “dual purpose” for grazing and grain, generally have a strong requirement for a period of cold temperature before the change to the reproductive phase.

After the appearance of approximately 6 leaves in the spring types, the head of the plant starts to progress up through the plant. This is achieved by the extension of the plant stem between the nodes or the internode. In most varieties grown in Australia, there will be 4 nodes detectable or 5 internodes expanded, the final internode is referred to as the peduncle.

As the crop enters this developmental stage, the demand for nitrogen increases dramatically as the plant begins to produce the tissues needed to create the stem. The amount and timing of the nitrogen required is dependent on the yield potential and the environment. For lower yielding areas such as the Mallee, the aim is to have any nitrogen needed to reach the target yield on the crop by the beginning of stem elongation (DC 30; see Picture Three below). Areas that have higher yield potential and cooler finishes, the timing of nitrogen applications to drive yield can be as late as the third or fourth node (DC3.3 or 3.4).

While the stem is elongating, the head is also undergoing development. The crucial stage of head development is approximately 2 to 3 weeks prior to flowering or booting (DC4) when the florets (individual flowers in the head) are being formed. Once again, environmental stresses such as moisture or high temperature can either decrease the number of florets being formed or reduce survival of formed florets.

After head emergence (DC5), the crop flowers (DC6), with the individual florets releasing pollen in a process called anthesis. This begins in the central section of the head and progresses to either end. Anthesis occurs inside the florets as wheat is self-fertile and the anthers are only visible outside heads afterwards.

After fertilisation occurs, there are three stages of grain development. Initially the grain size is determined (DC7), followed by the accumulation of starch (DC 8) and then ripening (DC 9).

The crop is at risk of frost from when the head emerges until early grain fill. The flowering window of the crop is always a trade-off between delaying flowering to avoid frost but not too late where yield could be affected by high temperatures and/or moisture stress. Ultimately, the choice of variety and sowing date should be made so that the crop flowers in the period where the risk of all three environmental stresses are minimised.

The drivers of Plant Phenology

Temperature

Temperature influences the development principally through two areas, rate of growth and the plant's response to temperature for influencing developmental phases.

Temperature and Vegetative Growth

As a general statement, plant vegetative growth increases as temperature increases. There is an upper and lower temperature limit where growth ceases. The lower limit for growth in Australia is generally accepted as 0° C, although studies have shown a broader range of lower limits, and the lower limit can change for a given developmental stage or variety.

Optimal temperature for growth is in the range of 20° -25° C.

Upper limit is generally regarded as 35° C, but crops have been shown to be able to acclimatise if they have previously been exposed to high temperatures.

In an attempt to describe the influence of temperature on crop growth, the concept of Degree Days is used to be able to predict crop growth stage. Degree Days are calculated by taking the daily average temperature (maximum plus minimum divided by 2) and subtracting the base temperature.

For example, if the daily maximum was 20° C and the minimum was 10° C, then the average daily temperature was 15 C and therefore the crop experienced 15 degree days for growth.

Development of the Plant in Response to Temperature

Germination and Emergence

Germination is the process of the seed breaking dormancy and producing the first root and shoot to break through the seed coat and emergence for the coleoptile to break the soil surface and the first leaf appears. Temperature, moisture and oxygen are needed to instigate this process. Minimum temperatures for wheat germination are in the range of 3.5° to 5.5° C, the optimum being 20° – 25° C and the upper limit being 35° C.

An estimate of the time needed for the crop to germinate can be calculated using degree days, with the range being 125 to 160 DD or if the soil temperature is 18° C, then approximately 8 days.

Vegetative Growth

Following emergence, the plant then produces leaves at a rate determined by temperature. The appearance of one leaf to the next is a constant in thermal time and the accepted figure is 100 DD. This period is also known as the phyllochron. There are variations to this figure, influenced by sowing date, but for the majority of crops sown in the late April to mid-June period, the phyllochron is 100 DD.

If the daily mean temperature is 15° C as per the previous calculation, then a leaf will appear every 6.7 days, or if it cooler and the daily mean is 10° C, then it will take 10 days for the next leaf to emerge.

Similarly, warmer temperatures during spring accelerate plant development. However when temperatures begin to approach the upper limits, they can have negative effects on productivity. Warm temperatures during grain fill create two competing processes inside the plant. Higher temperatures accelerate the rate of photosynthesis and hence the available material for grain fill. Similarly, higher temperatures increase the rate of grain fill – i.e. the time for grain fill is shortened. Unfortunately the shorter grain fill period is not compensated by the higher rate of photosynthesis and the overall effect if for smaller grain weight.

While temperature is the key driving plant development, the plant’s response is modified by vernalisation and day length.

Vernalisation

Vernalisation is the requirement to be exposed to cold temperatures in order for the reproductive phase to begin. Temperatures in the order of 1° – 12° C are needed to meet this requirement depending on varietal characteristics. Wheat varieties that have little or no vernalisation requirement are often referred to as spring types, and temperatures in the range of 7 to 18° C for brief periods will be sufficient for vernalisation. Wheats that have a strong vernalisation requirements are called winter types, and lower temperatures of between 0° and 7° C for several weeks are needed for vernalisation.

Vernalisation is a useful tool in that it gives an environmental cue to the plant on when is the most suitable time to transform to the reproductive phase, and so offer a greater sowing window.

Spring types will simply go through the vegetive phase and transform to reproductive based on the temperatures the plant is experiencing – i.e. sown early in March into warm soil and warm daily temperatures may reach reproductive phase by June and flower in August, increasing the risk of frost damage. Picture Four (below) shows Winter wheat (left) and Spring wheat (right) sown in March.

Day length

Wheat develops and flowers more rapidly when grown under long day conditions. Wheat is not an obligate day length plant (i.e. a plant that will not commence the reproductive phase until a certain day length requirement is met), but the change to reproductive phase can be delayed if the day length is too short. However the plant will flower eventually even if the “trigger” day length is not met.

In a day length sensitive variety, the transformation from vegetative to reproductive is delayed under short day conditions (i.e. winter) and will initiate more leaves.

Similar to vernalisation, there is a great range of sensitivity in the varieties grown. Many of the spring wheat varieties grown have some day length requirement which is a desirable characteristic as it allows some flexibility in sowing dates.

What does all this mean?

The aim of growing a wheat crop is to have the crop flower late enough to reduce the risk of frost, but early enough to ensure grain fill is not adversely affected by either moisture or temperature stress. Therefore the optimum flowering window is generally known for each district. However getting a crop to flower in this period is not easy as there are many variables such as sowing date, seasonal temperatures and available moisture that influence the crop phenology.

Sowing date is becoming harder to predict due to autumn breaks that are tending to occur later and the pessimist would suggest that late moisture stress and higher temperatures are likely to occur more often in the future.

An improvement on a risk basis are wheat varieties that have a longer sowing window that will flower at the optimal time for grain yields. These features are possible in a wheat variety with the incorporation of sensitivity to vernalisation and day length to modify the change from vegetative to reproductive growth.

Unfortunately most varieties, with the exception of the winter types, have little information on the sensitivity to either day length or vernalisation. However the combination of these two characteristics give a variety greater adaptability.

A characteristic such as vernalisation allows wheat to be sown at the first opportunity early in the autumn and be confident that it will remain vegetative until its temperature requirements are met and flower in late spring. In a high rainfall zone where summer rain is highly likely, theoretically spring sowings would remain vegetative for until late winter. In lower rainfall areas, the delay to the reproductive phase can mean that flowering occurs too late for the optimum grain fill.

Similarly a variety with that is sensitive to day length has a wider sowing window as the vegetative period would be extended and the flowering period delayed until the optimal period.