Phase durations in wheat will need to be optimised for crops in the High Rainfall Zone of south-west Victoria to achieve yield potential

Penny Riffkin[1] and Garry O'Leary[2]

[1] Department of Primary Industries, Hamilton, Victoria, 3300, Australia Email penny.riffkin@dpi.vic.gov.au
[2] Department of Primary Industries, Horsham, Victoria, 3400, Australia Email garry.o'leary@dpi.vic.gov.au

Abstract

Field experiments were conducted in 2008 and 2009 at Hamilton in the high rainfall zone of south-west Victoria, Australia to test assumptions of a proposed wheat ideotype for the region relating to optimum phase durations within the crops life cycle. The ability of wheat crops to produce sufficient shoots to form 400 ears/m^2 at harvest and a canopy with a green area index (GAI) of 6 from a foundation phase duration (sowing to GS31) of 650?C days (base=0?C) was tested. Results indicate that a thermal time of 650?C days is sufficient to produce the target number of ears/m^2 providing N is adequate. A GAI of 6 may be achieved from a foundation phase of 650?C days as long as this is combined with an adequate construction phase duration (GS31 to flowering). With a short foundation phase duration, the construction phase duration will also need to be increased to extend flowering later in the season to minimise the risk of exposure to spring frosts. These results support the assumptions of the proposed ideotype and indicate that new germplasm with different phenology will need to be discovered and developed for crops in this region to achieve yield potential.

Key Words

High rainfall zone, ideotype, phenology, canopy, shoot numbers, ear numbers

Introduction

The life cycle of wheat is divided into different phases as defined by key events. The three main phases include the vegetative or foundation phase (sowing to stem extension), the construction phase (stem extension to flowering) and the production phase (flowering to physiological maturity). To maximise grain yields it is important that these phases are timed to enable to crop to set a structure which optimises resource capture and partitioning and minimises climatic risks. The potential number of shoots is set during the foundation phase. These shoots will influence the size of the canopy and therefore the ability of the crop to capture sunlight as well as set the potential yield by producing fertile ears. The longer the duration of the foundation phase the greater the potential number of shoots. Not all shoots will survive to produce fertile ears but numbers sufficient to produce 400-500 ears/m^2 at harvest are considered optimum to maximise grain yield (Spink et al. 2000, Foulkes et al. 2002, Zhang et al. 2010). The canopy will reach a maximum size towards the end of the construction phase. The optimum maximum canopy size is estimated to have a green area index (GAI) of 6 cm^2/cm^2. Small canopies with a GAI less than 4 are unable to capture all incoming radiation, whereas canopies greater than 7 are considered inefficient (Sylvester-Bradley et al. 2008).

Crops in the High Rainfall Zone (HRZ) of southern Australia are believed to produce excessively large canopies, resulting in inefficient crops as evidenced by low harvest indices (Riffkin et al. 2003). Cropping in this region is relatively recent with most cultivars introduced from other HRZ regions of the world or from the traditional drier wheat belt in Australia. Hence crops are considered to be poorly adapted to this environment. An ideal wheat type or 'ideotype' has been proposed which identifies the optimum phase durations to maximise grain yield in the HRZ (Riffkin and Sylvester-Bradley 2008; Sylvester-Bradley and Riffkin 2008). This ideotype predicts that a foundation phase duration of 650?C days (base = 0^oC) will be sufficient to form enough shoots to generate a canopy size of GAI 6 and produce 400 ears/m^2. An experiment was conducted at Hamilton in south-west Victoria to test the assumptions relating to foundation phase duration.

Methods

Experiments were conducted at Hamilton Victoria (37^{o}49'S, 142^{o}04'E) in 2008 and 2009. Soil type in both years was a chromosol with mineral N levels prior to sowing 97 and 101 mg/kg (0-60 cm depth) for 2008 and 2009 respectively. Two wheat cultivars (Axe and Frelon) with contrasting foundation phase durations were sown on raised beds at two sowing times with two N fertiliser regimes. Axe is an early maturing spring wheat type with a short foundation phase and cv. Frelon is a long season winter type with a vernalisation requirement resulting in a long foundation phase when sown early. Cultivars were sown on April 29 and June 25 in 2008 and on May 5 and June 15 in 2009 with 100 kg/ha MAP (N10: P22: K0: S2) to achieve a target plant density of 250 plants/m^2 with a 15 cm row spacing. Nitrogen fertiliser was applied twice during the season in the form of urea at a rate of 75 kg N/ha to give a total rate of 160 kg N/ ha. Fertiliser was applied at sowing and at GS31 for the Early N treatment and at GS39 and GS65 for the Late N application. The experiment was a three factor random complete block design (RCBD) with four replicates giving a total of 32 plots. Annual rainfall was below the long-term average (LTA, 690 mm) in 2008 (628 mm) but higher in 2009 (724 mm).

Tiller numbers were determined at 3-4 weekly intervals from six, 1m drill rows set at permanent locations within each plot. Ear numbers from the same locations were determined at harvest. At key developmental stages, (GS31, GS39, flowering and maturity) dates were recorded and plant biomass and green area measured. Canopy size was determined as a measure of green area index (GAI cm^2/cm^2) and calculated as the surface area of green material as a proportion of the area of ground it occupied. Data was analysed through ANOVA using GenStat 9.1 (GenStat Committee 2003).

Daily minimum and maximum screen temperatures (^{o}C) and rainfall (mm) data was collected from the DPI weather station approximately 500 m from the experimental site. Thermal time (?C days) was calculated as the accumulation of daily mean temperature above a base temperature of 0^{o}C.

Results

Phenology

Cultivar Frelon flowered approximately 46 days later than Axe for sowing time 1 (ST1) with the difference diminishing to only 12 days at the second time of sowing (ST2). The foundation phase duration based on thermal time was shorter than the optimum of 650?C days proposed for the ideotype for Axe but was longer for cv. Frelon (Table 1). The foundation phase duration for the winter wheat was around 2.1 times that of the spring type for the earlier sowing times. This reduced to approximately 1.5 times the duration by ST2. Thermal time from GS31 to flowering was less for cv. Frelon than cv. Axe particularly for ST2 (difference of 30?C days for ST1 and 100?C days for ST2; mean of both years) (Table 1). The construction phase remained longer than the foundation phase for both sowing times for cv. Axe but for cv. Frelon this period was shorter. Hence the longer maturity of the winter wheat was largely due to the longer foundation phase.

Table 1. Thermal time (?C days, base 0^{o}C) from sowing to GS31 and from GS31 to flowering (GS65) for a spring type (cv. Axe) and a winter type (cv. Frelon) sown at 2 sowing times (April 29 and June 25 in 2008 and May 5 and June 15 in 2009).

		2008		2009	
Cultivar	Sowing Time	Sow- GS31	GS31- GS65	Sow- GS31	GS31- GS65
Axe	1	509	774	486	824

Axe	2	504	703	627	657
Frelon	1	1081	773	1034	765
Frelon	2	835	548	876	614

Shoot and ear numbers

Maximum shoot numbers were significantly higher for cv. Frelon than for cv. Axe ranging from 449 (cv. Axe ST2 in 2008) to 1388 (cv. Frelon ST1 in 2009). The first sowing time produced significantly higher shoot numbers than ST2 with the exception of cv. Axe in 2009 where the difference between sowing times was not significant (Table 2). The number of ears/m^2 ranged from 388 (cv. Axe ST2 in 2008) to 651 (cv. Frelon ST1 in 2009). Shoot survival (shoots producing fertile ears at harvest) was significantly greater for Axe than for cv. Frelon with most shoots forming fertile ears in cv. Axe whereas only about half the number of ears survived in cv. Frelon. In general, there was lower percent shoot mortality for the second time of sowing (Table 2).

Early applications of N fertiliser resulted in more shoots and ears/m^2 although differences were not always significant (data not shown). In 2008 there was a cultivar x N fertiliser interaction for shoot survival where late applications improved shoot survival for cv. Axe but reduced survival for cv. Frelon. This translated to significantly fewer ears/m^2 for cv. Frelon with the late application of N but no significant affect of N timing for cv. Axe.

The target number of ear/m^2 (400) was not achieved for either cultivar with for the second sowing time where N fertiliser was applied late in 2008 (cv. Axe 353; cv. Frelon 345).

Table 2. Shoot numbers, ears/m^2 and shoot survival for two wheat cultivars with different maturities sown at two sowing times in 2008 and 2009. LSDs are for all comparisons across cultivar and sowing time except shoot survival in 2009 where it is for cultivar only. Data are average values of N fertiliser rates.

		2008			2009		
Cultivar	Sowing Time	Max Shoots	Ears/m^2	Shoot survival	Max Shoots	Ears/m^2	Shoot survival
Axe	1	617	602	0.94	557	539	0.97
Axe	2	449	388	0.87	607	598	0.99
Frelon	1	1153	511	0.44	1388	651	0.47
Frelon	2	756	429	0.57	921	517	0.58
F Prob		0.029	0.065	<0.001	<0.001	0.001	ST = 0.05

CV= <0.001

LSD	144.2	48.2	0.5495	141.5	74.9	0.064

Canopy size

GAI at flowering varied from 2.4 (cm^2/cm^2) for Axe ST2, early N in 2008 to over 8 for Frelon ST1, early N in 2009. Canopies were significantly smaller for the second time of sowing compared to the first with the exception of Axe, early N application in 2009. Early applications of N fertiliser usually resulted in a larger canopy for ST1 but in general the differences were not significant for ST2 (Table 3).

Table 3. Green area index (cm^2/cm^2) for two wheat cultivars (CV) with different maturities sown at two sowing times (ST1 and ST2) with N fertiliser applied either Early (sowing and GS 31) or Late (GS 39 and flowering) in 2008 and 2009. In 2008 there was a ST x N interaction (Fprob 0.007, lsd 1.048) and in 2009 a CV x ST x N interaction (F prob <0.001 lsd = 0.487).

		2008		2009	
Cultivar	Sowing Time	Early N	Late N	Early N	Late N
Axe	1	6.88	5.51	4.83	4.87
Axe	2	2.44	2.75	4.91	3.51
Frelon	1	7.41	4.74	8.04	5.22
Frelon	2	3.04	2.97	2.56	2.67

Discussion

Shoot and ear numbers

Data from this experiment support the assumption of the ideotype that a foundation phase with a duration of 650?C days is sufficient to form enough shoots to produce at least 400 ears/m^2 at harvest. Although fewer shoots were produced by Axe, greater shoot survival resulted in a similar final number of ears/m^2 as for Frelon. This was despite the foundation phase duration for Axe being shorter than that recommended for the ideotype. Axe only failed to reach the target ear number when sown late with a late application of N fertiliser. The longer foundation phase for Frelon resulted in three times as many shoots being produced as required for target number of ears/m^2 at harvest for optimum grain yield. Shoot mortality was high for Frelon at more than 50% for the earlier time of sowing indicating an inefficient use of resource. A foundation phase of around 650?C days in this environment should be sufficient to produce enough ears to optimise yield and may result in greater efficiencies through reduced shoot mortality.

Canopy Size

Data from Axe ST1 with early N fertiliser applications in 2009 indicates that a foundation phase duration of 650?C days should be sufficient to produce an optimum canopy size with a GAI of 6. However, achieving this target GAI will be strongly influenced by management, in particular time of sowing. Canopy size was below optimum for ST2 even for Frelon where the foundation phase duration was around 850?C days and shoot numbers exceeded 750/m^2. This was most likely due to the significantly shorter construction phase duration for ST2 compared to ST1. Frelon produces very small leaves prior to GS31 whereas leaves that emerge later are considerably larger. A longer construction phase duration will therefore be required to allow for greater canopy expansion. For cv. Axe it appears that a short foundation phase will only produce a sufficient canopy size when combined with a longer construction phase which was only achieved with early sowing. In addition, if both the foundation and construction phases are short, then the full growing season will not be utilised and flowering will occur too early thus increasing the risk of exposure to frost. This supports the proposed phenology of the ideotype which indicates that a longer construction phase will be of benefit to crops in this environment (Sylvester-Bradley and Riffkin 2008).

Conclusion

Data support the assumptions for the ideotype that a foundation phase of 650?C days is adequate to set the crop up to achieve tiller number and canopy size targets. Evidence is also provided which indicates that a longer construction phase duration may also be required in this environment. Further field and modelling studies will need to be conducted to test the assumptions of the ideotype in relation to optimum duration of the construction phase. It is likely that new germplasm with different phenology than is currently available will need to be discovered and developed for crops in the HRZ to achieve yield potential.

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