Simulating leaf area duration to predict yield response to foliar fungicide in wheat and barley

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Abstract

Grain yields of wheat and barley are strongly related to post-anthesis leaf area duration (LAD). In water limited environments, LAD is primarily determined by post-anthesis water supply. Foliar fungicides applied at flag-leaf emergence (Z39) act to increase yield by maintaining LAD in the presence of fungal foliar diseases. Where post-anthesis water supply is adequate, fungicide application usually results in increased grain yield relative to plants not treated with fungicide. However, where post-anthesis water supply is limiting and LAD limited accordingly, there is usually no yield response to fungicide and in some cases a yield reduction. This presents a problem to managers who at Z39 must decide whether to apply fungicide as insurance against loss of post-anthesis LAD when water supply may well ultimately limit LAD.

In this paper, we validate the ability of the crop production model APSIM to simulate LAD in the absence of foliar disease and various degrees of water limitation. We then use model output to estimate yield losses in response to differing levels of LAD reduction arising from infection. We found that APSIM is adequately able to simulate LAD and corresponding yield under the influence of varying water supply. Based on this we derived a look-up table which estimates likely yield loss based on expected yield in the absence of disease and expected disease effects on LAD. It is proposed that the simulated relationship between LAD and yield be incorporated into the web-based decision support tool Yield Prophet[?] to provide dynamic, paddock specific likelihoods of yield response to fungicide.

Key Words

Wheat, barley, foliar fungicide, APSIM, Yield Prophet?

Introduction

Biotrophic foliar fungal pathogens of wheat such as stripe rust (*Puccinia striiformis*) and leaf rust (*Puccinia triticina*), and barley such as leaf rust (*Puccinia hordei*) and powdery mildew (*Blumeria graminis*) cause significant yield loss in Australian cereal crops. They also demand ongoing investment in control through resistance breeding and pesticides. Stripe rust of wheat alone is thought to cost the Australian wheat industry in the order of $127 million annually (Murray and Brennan 2008). Such pathogens largely act to reduce grain yield by decreasing the amount of green leaf area available for photosynthesis in the critical post-anthesis period rather than reducing the efficiency with which radiation is used for growth (Serrago et al. 2009). In the temperate climate of northern Europe, it has been demonstrated that foliar fungicides are able to prevent yield losses in the presence of disease by maintaining green leaf area in the crop canopy post-anthesis, allowing crop plants to absorb more incident radiation (Bryson et al. 1997).

Foliar disease management in Australia is further complicated because grain yields in most areas and seasons are limited by water-supply, which is highly inconsistent relative to most production environments globally. As a result, water-supply in the post-anthesis period is the ultimate driver of leaf area duration (LAD) and radiation interception. This poses a challenge for managers who must decide at flag leaf emergence (Z39) whether to invest in foliar fungicide when it is unclear if a yield response due to maintenance of LAD will be forthcoming, since water-supply might be a stronger limit to LAD, under which circumstances no increase in yield and return-on-investment is likely. Improving the decisions made by crop managers therefore represents significant potential gains in productivity and profitability.

In order to assist farmers and advisers manage crop inputs in Australia's highly variable climate, the APSIM-based (Keating et al. 2003) online decision support system Yield Prophet? (Hochman et al. 2009b) was released in 2004. This system provides managers with probabilities of yield outcomes and likely response to inputs based on current seasonal conditions and historic climate variability. Managers can then choose to make a decision at a level of investment risk with which they are comfortable. This system has been readily adopted and has improved the ability of farmers to match crop inputs, mainly nitrogen fertilizer, to seasonal yield potential (Carberry et al. 2009). Because the profitability of fungicide application is essentially a question of managing climate variability, potential exists to further develop Yield Prophet? to assist crop managers make foliar fungicide applications based on forecast yield probabilities and likely yield responses due to preservation of photosynthetic leaf area. This paper describes the first steps taken to assess the feasibility and validity of such an approach.

Methods

Sensibility test

The ability of APSIM to accurately simulate soil water balance and cereal crop growth and yield has been repeatedly demonstrated (Carberry et al. 2009; Hochman et al. 2009a). However, as this study relies on sensible simulation of the relationship between leaf area duration and yield, the model was validated using data taken from the time-of-sowing experiment conducted by Fischer & Kohn (1966) at Wagga Wagga (S35.05? E147.35?) in 1962. The APSIM v.7.1 SoilWat module was parameterised using reported measurements of bulk density, starting soil water, crop lower limit and drained upper limit (Fischer and Kohn 1966). The APSIM Wheat module was parameterised for the tall wheat cultivar Heron used in the experiment by changing the number of grains per gram of stem to 12.0 (Fischer 1979), reducing the maximum grain size to 39 mg (Fischer and Kohn 1966) and optimising thermal time to the end of the juvenile stage and vernalisation sensitivity to fit reported flowering dates. The simulation uses daily climate data taken from the Wagga Wagga Agricultural Institute (station no. 73127) accessed through the patched point dataset (http://www.longpaddock.qld.gov.au/silo/).

Relationship between leaf area duration and yield

APSIM was used to simulate leaf area duration and yield of barley in four locations across southern Australia (Table 1) with soil characterisations taken from the APSoil database (www.apsim.info/Wiki/APSoil.ashx). Crops were sown in the simulation if more than 15 mm of rain fell over a three day period between 7 May and 15 June at the end of which they were sown regardless. Nitrate in the top three soil layers was maintained above 100 kg/ha so that simulated yields represent water-limited attainable yield. The model was run over a 100 year period and the relationship between LAD and yield plotted.

Table 1. Locations, met stations, APSoil files and APSIM barley cultivars used in simulations of LAD and yield.

Location	Patched point station no.	APSoil no.	APSIM Cultivar
Munglinup WA	12281	450	Baudin
Hart, SA	21000	026	Flagship
Lubeck, Vic	79028	746	Buloke

Inverleigh, Vic	90167	737	Capstan

Results and discussion

APSIM was able to adequately simulate the relationship between post-anthesis leaf area duration and yield reported by Fischer & Kohn (Figure 1). Zadoks stage 65 is used as the starting point for the calculation of LAD from the simulation, however the result is sensitive to the stage nominated and it is unclear how this relates to 'flowering' as reported by Fischer & Kohn (1966). Within this limitation, we conclude that APSIM may be usefully used to explore the relationship between post-anthesis LAD in cereals and yield in Australian environments.

Simulation output for the four Australian environments showed a strong relationship between post-anthesis LAD and yield to which a common curve could be fitted (Figure 2). The positions on the curve of yields from different locations are due to the variability of the local climate, mainly timing and amount of rainfall. Because the principal mechanism of yield reduction due to foliar fungal cereal pathogens is through reduction in LAD and subsequent radiation interception and not reduced RUE (Bryson et al. 1997; Serrago et al. 2009) it follows that yield corresponding to a given LAD resulting from fungal infection should be equivalent to the same LAD resulting from water limitation (this assumption is being experimentally tested in the 2010 growing season).

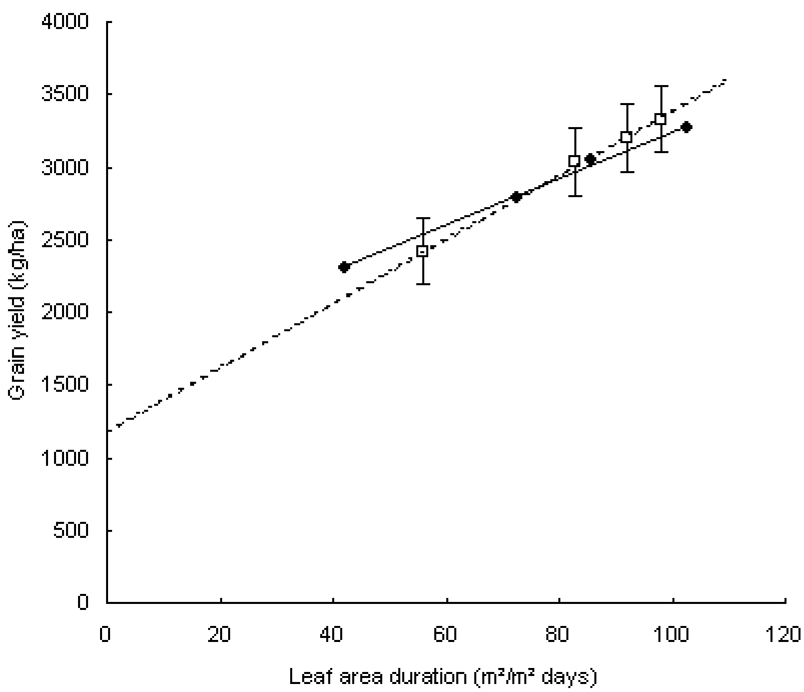

Figure 1. The relationship between grain yield and leaf -rea duration after flowering reported by Fischer & Kohn (1966, □) and as simulated by APSIM (●). The linear function fitted to the observed points (---) is of the form y=22.1x +1170 and that fitted to the simulated values (—) is of the form y=16.2x +1633. Error bars are +/- least significant difference of observed grain yield data (P=0.05).

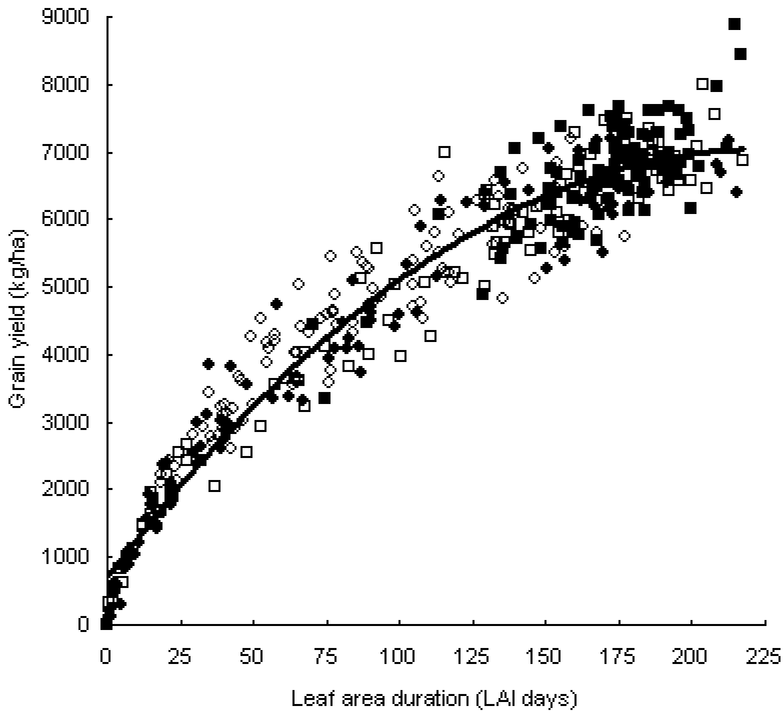

Figure 2. The relationship between simulated grain yield and leaf-area duration in barley from APSIM at Munglinup (○), Hart (□), Lubeck (●) and Inverleigh (■). The quadratic function fitted to the observed points (▬) is of the form y= = -0.126x^{2} + 56.5x + 718.4 (R?=0.94).

The relationship between LAD and yield described by the fitted curve in Figure 2 can be used to derive a look-up table showing expected yield reductions due to decreases in LAD at different yield potentials (Table 2). The table in itself comprises a simple form of decision support that can be used by managers in conjunction with estimates of yield potential to indicate likelihood and magnitude of a yield response to applications of foliar fungicide. It is also proposed that this relationship be used with yield probabilities generated by Yield Prophet[?] to indicate potential yield losses at a range of different yields and infection severities. However, how varietal susceptibility, timing of fungal infection and prevailing weather influence LAD is an unknown parameter. That is, in its current form managers would need to provide their own assessment of percentage reductions in LAD likely if no control is applied, and this would be difficult to estimate. A fruitful area of future research would be to relate pathogen type, cultivar susceptibility and timing of infection with percentage reductions in LAD relative to a treated control.

Table 2. A look-up table derived from the fitted function in Figure 2 which can be used to estimate yield loss due reductions in LAD relative to an expected yield of a healthy crop and anticipated level of LAD reduction.

	Expected reduction in post-anthesis leaf area duration							
Expected yield of healthy crop (t/ha)	**5%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**
	Estimated yield of diseased crop							
1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
2.1	2.1	2.0	1.8	1.7	1.6	1.4	1.3	1.1
3.3	3.2	3.0	2.8	2.6	2.3	2.1	1.8	1.5
4.4	4.3	4.1	3.8	3.5	3.1	2.8	2.4	2.0
5.5	5.3	5.1	4.8	4.4	3.9	3.5	3.0	2.5
6.3	6.2	6.0	5.7	5.2	4.8	4.2	3.6	3.0
6.9	6.8	6.7	6.4	6.0	5.5	4.9	4.3	3.5

Conclusion

APSIM is able to sensibly simulate the relationship between post-anthesis LAD and grain yield as influenced by weather (largely water supply), and could be a useful tool for investigating likely yield losses due to foliar fungal infections across a range of environments. Potential exists to develop Yield Prophet[?] output such that it is able to provide objective assessments of yield losses due to foliar fungal infections. However, further experimental work is required to better quantify how pathogen type, cultivar susceptibility, timing of infection and weather act to reduce post-anthesis LAD.

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References

Bryson RJ, Paveley ND, Clark WS, Sylvester-Bradley R, Scott RK (1997) Use of in-field measurements of green leaf area and incident radiation to estimate the effects of yellow rust epidemics on the yield of winter wheat. European Journal of Agronomy 7, 53-62.

Carberry PS, Hochman Z, et al. (2009) Re-inventing model-based decision support with Australian dryland farmers. 3. Relevance of APSIM to commercial crops. Crop & Pasture Science 60, 1044-1056.

Fischer RA (1979) Growth and water limitation to dryland wheat yield in Australia: a physiological framework. The Journal of the Australian Institute of Agricultural Science 45, 83-94.

Fischer RA, Kohn GD (1966) Relationship between evapotranspiration and growth in the wheat crop. Australian Journal of Agricultural Research 17, 255-295.

Hochman Z, Holzworth D, Hunt JR (2009a) Potential to improve on-farm wheat yield and WUE in Australia. Crop and Pasture Science 60, 708-716.

Hochman Z, Van Rees H*, et al.* (2009b) Re-inventing model-based decision support with Australian dryland farmers: 4. Yield Prophet? helps farmers monitor and manage crops in a variable climate. Crop and Pasture Science 60, 1057-1070.

Keating BA, Carberry PS*, et al.* (2003) An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267-288.

Murray GM, Brennan JP (2008) The Current and Potential Costs from Diseases of Wheat in Australia. GRDC, Barton, ACT (www.grdc.com.au/uploads/documents/GRDC_WheatDiseaseLoss_Report_final.pdf)

Serrago RA, Carretero R, Bancal MO, Miralles DJ (2009) Foliar diseases affect the eco-physiological attributes linked with yield and biomass in wheat (*Triticum aestivum* L.). European Journal of Agronomy 31, 195-203.