Is there a value in having a frost forecast for wheat in the South-West of Western Australia ?

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Abstract

Frosts around flowering frequently cause large yield losses in wheat in parts of the Western Australia wheat-belt. Managing frost risks is a balancing act between the crop flowering too early and possibly suffering frost damage and sowing later and therefore flowering later, but yielding less because the crop suffers water and heat stress. To maximize yield potential from early sowing and minimize yield losses from frost, the optimum sowing window with an appropriate cultivar needs to be determined. In this project we used the validated APSIM-Wheat model and long-term weather data to define potential yields and potential frost damage for different sowing dates, for three locations, three wheat cultivars and two soil types. The simulation experiments provided information on balancing the yield penalty of delayed sowing and potential frost damage from early sowing. In general, the results showed a steep decline of wheat yields with delayed sowing dates which was larger than the average decline from frost damage. A seasonal frost forecast to delay sowing in high frost risk years might only be warranted in severe frost risk areas. However, breeding for more frost tolerant wheat cultivars could increase the productivity of wheat in the frost-prone regions of Western Australia.

Key Words

Yield, APSIM-Wheat model, flowering, time of sowing

Introduction

Risk of yield loss in wheat due to spring frosts around the flowering stage is a constraint to wheat yield in some parts of the wheatbelt of Western Australia (WA). The occurrence of frost events is highest in late winter and declines into spring. In frost prone areas, late sowing of wheat to delay flowering into late spring to avoid the frost has been a traditional approach to minimise frost damage. However, wheat yields also decline with a delay in sowing date and flowering time due to the declining rainfall and increasing high temperatures during late spring. There is a trade-off between flowering early to get optimum rainfall and mild temperatures during grain fill, but with a higher risk of frost and flowering later to reduce frost risk, but with the less optimum water supply and increasing risk of high temperatures during grain fill. Due to the nature of frost events, it is difficult to obtain non-frosted and frosted yields under the same experimental conditions, that is, all the factors are the same except for the incidence of frost. Consequently there is a lack of published data on the effect of frost on yield.

One strategy used by growers is to delay sowing in frost prone areas. But the cost associated with reduced yield potential with delayed sowing can be greater that the actual cost of frost losses over time. The current farmers practice is to minimize frost damage by managing time of sowing and cultivars to maximize average yield in the long term. For example, in Wandering the frost risk would be too high for any combination of sowing date and cultivar and therefore the farmers are choosing more frost tolerant crops than wheat, e.g. barley and oats. In Narrogin, where the frost risk is moderate, the current strategy is to avoid early sowings and to sow wheat only after mid May. In Cunderdin, where the frost risk is low but the yield decline with sowing date is large, the current strategy is to sow as early as possible, despite a low frost risk.

In this study we tried to determine the potential yield gain from having a frost forecast enabling growers a) to delay sowing (or change cultivars) in seasons with a higher than average frost risk, and b) to sow earlier in years with a lower than average frost risk.

Hypothesis: A frost forecast at the beginning of the season would allow farmers to adjust management for that particular year to increase yields (e.g. if high occurrence of frost is forecasted, then delay sowing or sow late flowering cultivars results in higher yields compared to the standard practice).

Material and Methods

Crop simulation model

We used the validated APSIM-Wheat model (v. 6) (Keating *et al*., 2003) and historical weather data for the period 1957-2008 to define potential yields and potential frost damage for three locations in the Western Australian wheat-belt. The three locations, Wandering, Narrogin and Cunderdin have average annual rainfall of 517, 441 and 329 mm, respectively. Long-term simulations were run for seven times of sowing (sowing at 15 days intervals from the 25th of April to the 9th of July), three wheat cultivars (early, medium and late maturity types) and two soil types (clay duplex and deep sand). Crop management was simulated to reproduce current best practices in each location. The simulation experiments provided information on potential yields and yield damage from frost events with sowing date and the interactions with season, soil type and cultivar. The soil type had an effect on yield through the amount of water available to the crop but the effect of soil colour (albedo) on frost was not accounted for in the model.

Frost and yield relationship

Using data from the frost events in 1998 in Western Australian (Knell 2001) and unpublished data (Biddulph*, pers comm*.) we developed a semi-empirical relationship between minimum temperature around flowering and grain filling and yield losses due to frost in wheat. Additional data were from GRDC project DAW00162. Based on these data we estimated that screen temperatures below 2, 1 or 0 ˚C, during flowering would cause 20, 30 or 40 % yield reduction due to frost, and that temperatures below 0 ˚C during grain filling would cause a further 20 % yield reduction. Note that this reflects observed average yield damage from frost and might underestimate damage observed from more severe frost events. Note also that screen temperature is taken at 1.2 m height and is usually higher that the temperature at head height. Using this model of relative frost damage, we converted the simulated potential wheat yields into frost-affected yields or yields with yield penalties due to low temperatures during flowering and grain filling. The yield reductions due to frost obtained using this model have been compared to common farmers risk perception of frost, and they compared well. However, as we concentrated on an “average frost damage” at this stage, caution is required regarding the current conclusions.

Frost forecast

To define the frost forecast, we counted the number of days with temperature below 2 ˚C in September in the last 50-year period and divided the long term record into low or high frost risk years. The current management for frost is to reduce frost damage by managing time of sowing and cultivars to control flowering dates to maximize average long-term yields. That is, based on the break of the season (i.e. first significant rainfall in autumn) at a given year, the growers will first decide whether to sow or to delay sowing and then will chose the cultivar class (early, medium or late) that would maximises the long term average yield. For example, given a break of the season around the 10 May (DOY 130) farmers in moderate frost risk locations, such as Narrogin, will sow a late flowering cultivar. If the break occurs around the end of May (DOY 145) they would change to a medium or early flowering cultivar.

If a frost forecast could predict the occurrence of spring frost when growers are making seeding decisions in the previous autumn, this may allow growers to strategically change the sowing date and cultivar choice accordingly. To quantify the potential value of a frost forecast, the long-term average yields from not using a frost forecast were compared with the long-term average yield using a frost forecast.

Results

The simulations showed a steep decline of wheat yields to delays in sowing after a critical date (Fig. 1). Yield losses ranging from 3 to 8 % depending on location and cultivar occurred for each week that sowing was delayed after about mid May. Lower rainfall locations and long season cultivars experienced greater yield reductions with delayed sowing. The results indicated that late flowering cultivars would be preferred for early sowings in all locations and soil types. For sowing opportunities after the end of May, there were no marked differences between cultivars. The simulations also showed a steep decline of frost risk at flowering with delay in sowing (Fig. 2). Frost risk was defined as the chance of having at least one day with minimum temperature below 2 ^{o}C during the flowering period. The flowering period was obtained from the APSIM runs and ranged between August to November depending on sowing date, cultivar and location (Table 1). The frost-yield model gave yield reductions of 20 to 60 %, which were consistent with farmers and consultants experience in the different locations. We combined the frost damage model with the APSIM simulated potential yields to obtain frost-affected yields, shown as average yields for the 50 years period in Figure 3 (dotted lines in Fig. 3).

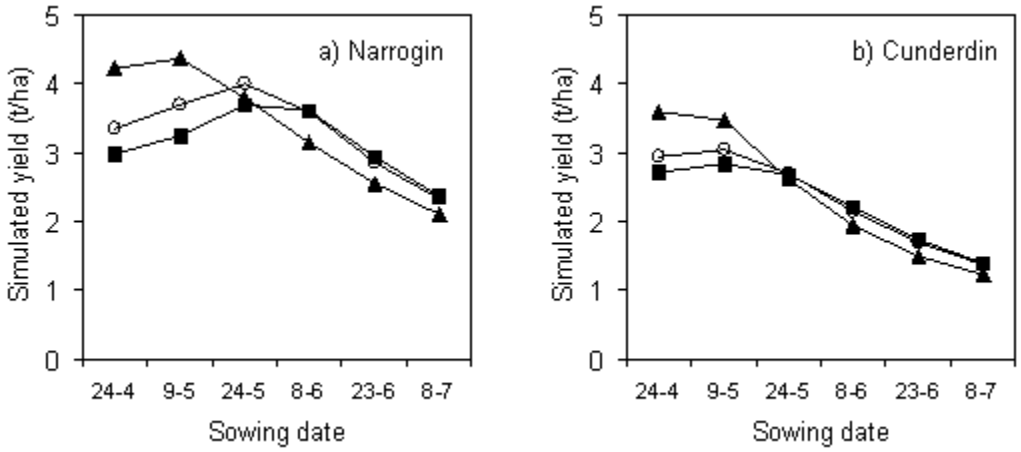

Fig 1. Long term average simulated yields versus sowing date for a) Narrogin and b) Cunderdin for an early (■), medium (○) and late (▲) flowering cultivar on a heavy soil.

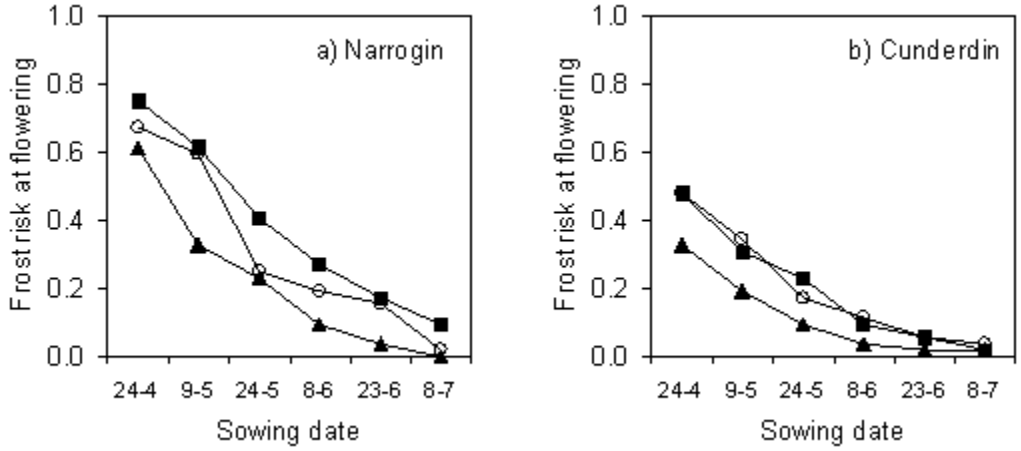

Fig. 2. Frost risk around flowering versus time of sowing for an early (■), medium (○) and late (▲) flowering cultivars for a) Narrogin and b) Cunderdin on a heavy soil. Frost risk defined as the chances of having at least one day with minimum temperature below 2 ˚C.

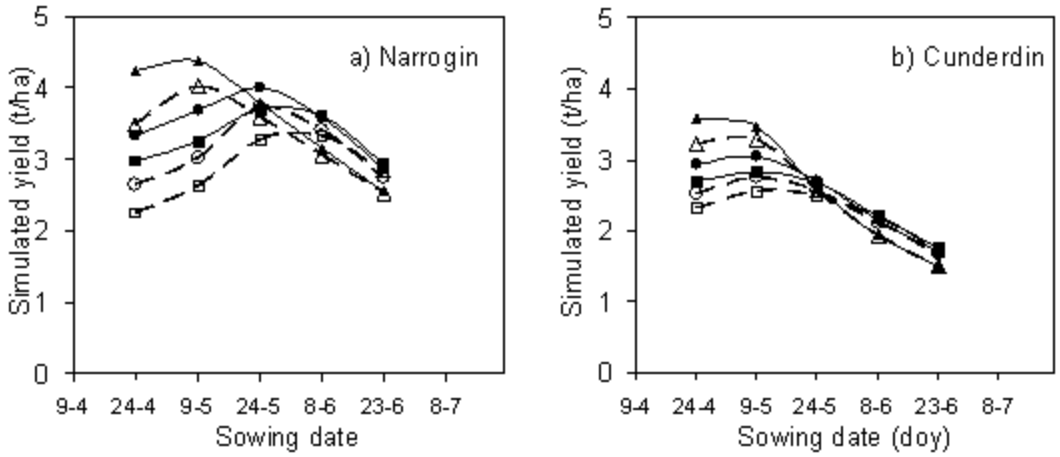

Fig 3. Simulated potential yields (no frost damage, solid lines) and frost-affected yield (dashed lines) versus sowing day for an early (■), medium (○) and late (▲) flowering cultivars for a) Narrogin and b) Cunderdin on a heavy soil.

The proposed management is to adjust the sowing date for the particular season using the forecast of low or high frost risk year (we did this retrospectively, so it assumes perfect forecast). We sowed the crop according to current practices in the low frost risk years or delayed the sowing by 15 days in the high frost risk years of the 50 year simulation study. Table 1 shows the flowering dates and average yields for the 50 year period using current management or using the frost forecast at the beginning of the season.

Given the yield sensitivity to frost used in our model and assuming a frost forecast of low or high risk in September only, there seems to be no benefit in using a frost forecast to adjust crop management (Table 1). This might be different when considering more severe frost damage instead of the average damage. As an alternative to frost forecast in managing frost, a hypothetical wheat cultivar with one degree more tolerance to low temperatures was simulated. Such a new cultivar would significantly improve yields (Table 1).

The initial approach tested in this model may be useful in further defining the sensitivity of the interaction between potential frost damage and the actual yield loss associated with delayed sowing to minimise frost risk. It will be further developed to try and answer questions about what level of frost damage does the yield penalty outweigh the benefit from frost risk? How accurate does a frost prediction need to be to enable cost effective management decisions? For example, do we just need to predict the years when we get severe damage, and avoid growing frost susceptible crops in those years? What is the effect of reducing frost susceptibility of the crop through agronomic and genetic improvements? Will a 0.2? 0.5?, 1.0?C improvement have a real effect?

Table 1. Current optimum sowing dates, corresponding flowering dates and simulated grain yields (t/ha) for three locations and two wheat cultivars (Late=Late flowering cultivar; Medium = Medium flowering cultivar). Delayed sowing date due to frost forecast, corresponding flowering dates and simulated grain yields.

	Wandering (High Rainfall)		Narrogin (Medium-High Rainall)		Cunderdin (Medium Rainfall)	
	Late	Medium	Late	Medium	Late	Medium

Current optimum sowing date	10 May	25 May	10 May	25 May	10 May	10 May
Average flowering date for current sowing	27 Sep	26 Sep	27 Sep	25 Sep	11 Sep	28 Aug
Average yield with frost damage	3.2	2.9	4.0	3.7	3.3	2.8
Delayed sowing date due to frost forecast	25 May	9 Jun	25 May	9 Jun	25 May	25 May
Average flowering date for delayed sowing	10 Oct	8 Oct	10 Oct	8 Oct	26 Sep	13 Sep
Average yield using a frost forecast	3.1	3.0	4.0	3.7	3.0	2.6
Average yield with frost tolerant (1 ^{o}C) cultivar	3.6	3.3	4.2	3.9	3.4	2.9

Conclusion

The results indicated that changing crop management based on a frost forecast for below or above median frost risk in September would not improve wheat yields compared to managing for the average long-term frost risk due to the assumption of average frost damage. Considering more severe observed frost damage might make a frost forecast viable. However, a hypothetical new cultivar with 1 ^{o}C more tolerance to frost would significantly improve yields in the frost-prone region of the Western Australian wheat-belt.

References

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