Simulating grain and grazing yield of diverse wheat genotypes in the HRZ

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Abstract
There is growing interest in the potential to expand cropping into Australia's higher rainfall zone (HRZ). Grain yield and grazing potential from 4 different wheat phenology types sown fortnightly from early March to late June was simulated for 50 years using APSIM at 13 locations across Australia's HRZ. The 4 wheat cultivars represented slow-winter (e.g. Revenue), fast-winter (e.g. Wedgetail), mid-spring (e.g. Gregory) and fast-spring (e.g. Lincoln) maturity types. Potential grazing days were obtained by simulating sheep grazing crops at 25 DSE/ha up until Zadoks stage 30. Optimal sowing dates for each maturity type at each location were matched to the flowering window when the risk of frost and heat stress was lowest. Overall, we found there is significant potential for dual-purpose use of winter wheat cultivars across all regions of Australia's HRZ. Simulated mean wheat yields exceeded 6 t/ha at most locations in the HRZ and were highest (8-10 t/ha mean) in southern Victoria and lowest (5-6 t/ha average) in south-west WA. Highest grazing days were achieved from winter cultivars sown early (March to mid April) which could provide 1700-3000 DSE.days/ha of grazing; this was 2-3 times higher than from grazing spring cultivars (200-800 DSE.days/ha). However, at locations with Mediterranean climates, lower frequency of early sowing opportunities before mid-April (<30% of years) limited the potential utility of winter cultivars. The simulations also emphasised the importance of early sowing, sufficient N supply and sowing densities to maximise grain and grazing potential from crops in the HRZ.

Key words
Dual-purpose, grazing, yield, model, APSIM, cultivar, sowing time

Introduction
There is significant potential and interest to expand cropping into Australia's HRZ where the longer growing season (> 6 months) is thought to offer high grain yield potential, though current yields are limited due to a range of agronomic and edaphic factors (Zhang *et al*. 2006). Dual-purpose crops have been increasingly used in the higher rainfall areas of south-eastern Australia (over 300 000 ha are now sown), where they provide grazing for livestock during winter and later are allowed to regrow to produce grain. Dual-purpose use of crops has the capacity to increase overall profitability and productivity by 25-75% compared to grain only crops (Bell et al. 2014). With the large production and economic benefits possible from dual-purpose crops the scope to expand their use from their traditional areas to new regions of the HRZ requires clarification. This national simulation analysis across Australia's HRZ aimed to quantify the frequency of sowing opportunities, grain yield and grazing potential from a range of wheat phenology types and the influence of sowing date, nitrogen availability and crop density (more detailed analysis can be found in Bell et al. 2015).

Methods
Wheat crop grain yield and grazing was simulated over 50 years at 13 locations distributed across Australia's HRZ using representative soils and long-term climate records from each location. The soil and crop modules from the Agricultural Production System SIMulator (APSIM) were configured in combination with the GRAZPLAN animal models (Holzworth et al. 2014) to simulate potential sheep grazing, and ungrazed crops were used to predict potential grain yield. At all locations a factorial analysis included nine sowing dates simulated at 2-weekly intervals from 8 March to 28 June; 4 different cultivars representing slow-winter (Revenue), fast-winter (Wedgetail), mid-spring (Gregory) and fast-spring (Lincoln) maturity types; 4 levels of N availability (50, 100 and 150 kg N at sowing and unlimited N supplied throughout the season); and 4 plant densities (50, 100, 150, and 200 plants/m^2). For each combination of cultivar by sowing date, risks of frost and heat stress were estimated by categorizing low and high temperature occurrences into mild, medium and severe stress events (Table 1). Using the frequency and intensity of these events that occurred during the critical phenological period around flowering, 'safe' sowing windows for each phenology-type at each location were identified which minimised the risk of heat and frost events. This corresponded to a 18-24 day optimum flowering window when the average frequency of frost stress events (min. temp < 2^{o}C) was less than 2 and average frequency of heat stress events (max temp > 32^{o}C) were less than 1.

In all simulations, soil water content was set on the 1 February each year at 60% of plant available water with the profile filled from the top (dry at the bottom). To ensure simulated outcomes were produced for all sowing dates and years, the top 30 cm was wet to field capacity on the specified sowing dates to ensure crop establishment; the sowing opportunity for each sowing window was analysed separately (see below). All wheat crops were topdressed with 100 kg N/ha as urea at Zadoks stage 31 and available nitrate was set to a minimum of 50 kg N/ha at sowing. Grazing was simulated using 45 kg wethers (a dry sheep equivalent (DSE) at a stocking rate of 25 head/ha; hence, the predicted DSE.grazing days (DSE.days/ha) from the crop was calculated as the product of the stocking rate and the grazing period (days). Grazing commenced when biomass reached 1500 and 400 kg/ha in winter and spring cultivars, respectively. Sheep were removed when either crop green biomass fell below 400 or 100 kg/ha in winter and spring cultivars, respectively, or when the crop reached simulated Zadoks stage 30 in winter cultivars or 750 ^{o}C.d for Gregory and 600 ^{o}C.d for Lincoln; thermal time was preferred as a predictor of stem elongation in the spring maturity types.

To provide information on the likelihood and riskiness of sowing on specific dates, long-term climate records (1889-2010) for each location were used to analyse the frequency of a sowing opportunity. A sowing opportunity was defined as rainfall exceeding pan evaporation over a 7 day period (Unkovich 2010). Risk of failure to establish crops due to a 'false break' was calculated as the percentage of sowing opportunities in that 'sowing window' (i.e. 2-week period) that were followed by a 4 week period without any further effective rain (rainfall > evaporation over 7 days).

Results

Grain and grazing potential

Opportunities to successfully integrate dual-purpose crops were evident in all regions, but the best and most likely options in terms of varietal selection and sowing date varied. The analysis suggested that on average it is possible to obtain > 1700 DSE grazing days/ha and grain yields of 5.5-8 t/ha from early-sown dual-purpose winter wheat cultivars across locations (Fig. 1). The highest average potential grain yields were 8-10 t/ha from an early-sown slow-winter cultivar in the southern temperate high rainfall zone (i.e. Hamilton, Inverleigh, Bairnsdale, Cressy and Delegate; Fig. 1). In locations with a Mediterranean climate (*e.g.* Kojonup, Esperance and Naracoorte), highest average yields were less (up to 6-8 t/ha) and achieved from the fast-winter cultivar sown early (Fig. 1). On the slopes and tablelands of central and northern NSW (i.e. Young, Quirindi, Armidale), highest average simulated grain yields were ~ 6 t/ha from early-sown winter cultivars (Fig. 1). The average simulated yields were lowest at Pittsworth (Fig. 1). These potential yields agree closely with those obtained in experimental studies across the HRZ.

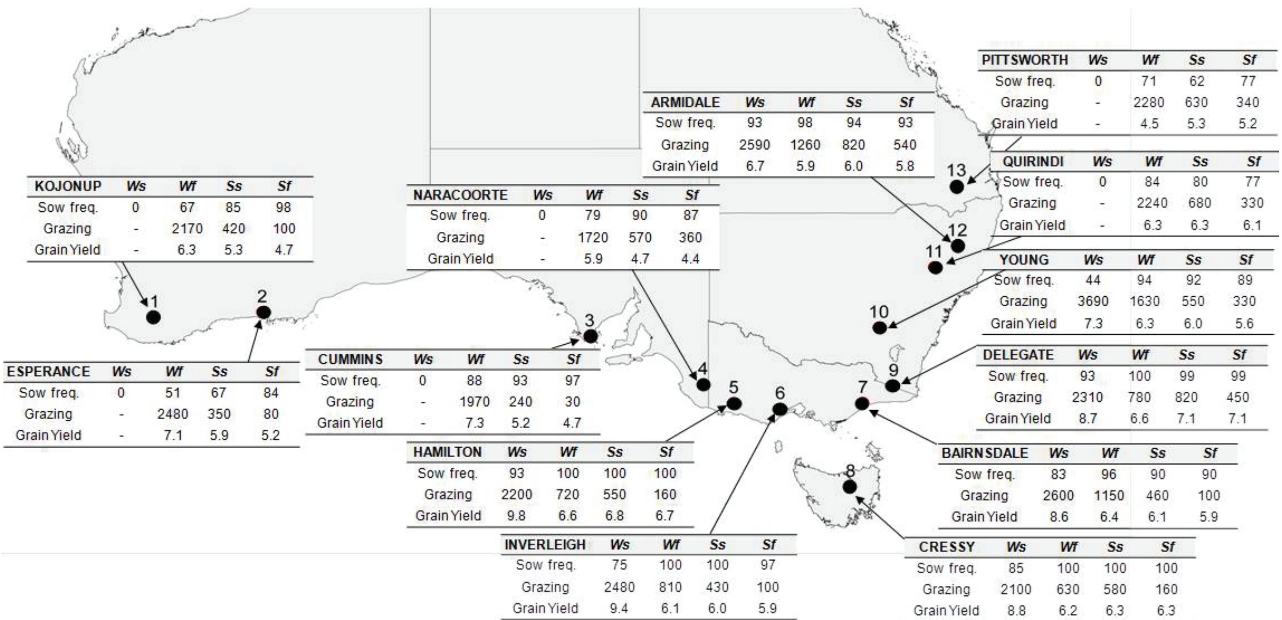


Figure 1. Simulated potential (N unlimited) grazing days (DSE.days/ha), potential grain yield (t/ha) and probability of a sowing opportunity (% of years) for predicted safe sowing windows for 4 wheat maturity types (Ws - winter slow e.g. Revenue, Wf – winter fast e.g. Wedgetail, Ss – spring slow e.g. Gregory, Sf – spring fast e.g. Lincoln) for 13 locations across Australia's HRZ.

In most environments, highest simulated grain yields came from earliest sown winter cultivars which were higher than those achieved with spring cultivars; the exception was Pittsworth (Fig. 1). In the cool temperate environments typical of the HRZ, the slow-winter cultivar had the highest simulated yield across all sowing dates, although spring cultivars approached similar potential yields from sowing dates after the end of May (Fig. 1).

Winter cultivars provided the most grazing potential with a long period of grazing before the crop reached stem elongation; crops could be grazed for a period of up to 100 days in some environments. In all environments except Naracoorte, more than 2000 DSE.days/ha on average could be achieved from dual-purpose winter wheat sown in March or early April (Fig. 1). By comparison spring cultivars offered significantly less grazing than from the winter cultivars. Nonetheless, in many environments the slower maturing spring cultivar could be grazed for 16-32 days and provide 400-800 DSE.days/ha (Fig. 1). The fast developing spring cultivars offered the least grazing potential, typically less than 400 DSE.days/ha, and limited grazing opportunities in some environments using the grazing rules applied here (e.g. Esperance, Cummins). These predicted forage and grazing yields from dual-purpose crops are consistent with experimental data in regions where this has been measured.

Sowing opportunities

Sowing windows that minimised frost and heat risk during flowering varied amongst locations and maturity types; this typically changed from winter to spring maturity types in early May. In many of the HRZ locations sowing opportunities frequently occurred prior to the safe sowing window for spring wheat cultivars. In the locations with a Mediterranean climate, sowing opportunities before mid April were infrequent (<30%) and risky due to a high chance of false breaks (Table 1). In the southern temperate locations, the likelihood of a sowing opportunity increased and > 30% of years would experience a sowing opportunity in any fortnightly period from mid March (Table 1). In the northern locations, sowing opportunities also occur in 27-50% of years in each fortnight throughout March and April (Table 1). The cumulative probability of a sowing opportunity occurring in the 'safe' sowing window for each maturity type is shown in Figure 1. This shows that for the HRZ locations there are sowing opportunities for a winter cultivars in over 50% of years (> 80% in most locations considered here).

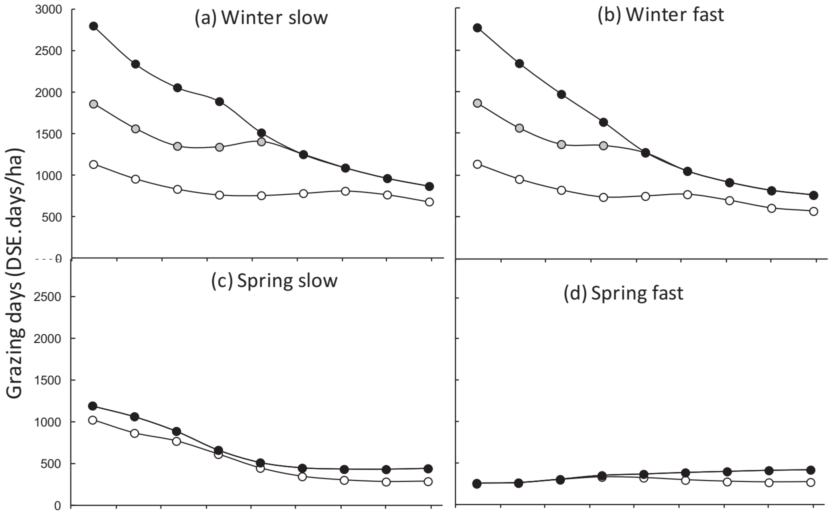
Figure 2 clearly demonstrates the importance of early sowing of dual-purpose wheat crops to maximise their grazing potential across a range of environments. Each week delay in sowing of winter cultivars reduced grazing potential by 200-250 DSE/days/ha. Grazing potential of spring cultivars was less overall and delayed sowing had far less effect on their grazing potential.

Table 1. Frequency of years (%) with a sowing opportunity (rainfall > pan evaporation over 7 days) and likelihood of a false break (in brackets) with no further effective rain (i.e. rainfall < pan evaporation over 7 days) in the subsequent 4 weeks for each fortnightly period from 1 March to 15 June at 13 locations across Australia's high rainfall zone.

Location	1-15 Mar		15-31 Mar		1-15 Apr		15-30 Apr		1-15 May		15-30 May		1-15 Jun	
Kojonup	5	(67)	8	(70)	19	(35)	21	(15)	48	(2)	79	(0)	88	(0)
Esperance	7	(67)	13	(44)	23	(29)	28	(29)	41	(2)	68	(8)	73	(3)
Cummins	3	(50)	7	(50)	17	(29)	30	(8)	51	(5)	76	(3)	85	(2)
Naracoorte	2	(100)	11	(43)	16	(40)	36	(16)	52	(5)	78	(2)	86	(1)
Hamilton	6	(71)	20	(17)	30	(16)	57	(4)	67	(2)	86	(0)	89	(1)
Inverleigh	17	(57)	25	(29)	38	(20)	52	(10)	60	(3)	83	(1)	84	(1)
Bairnsdale	28	(44)	30	(27)	32	(21)	46	(27)	49	(8)	60	(14)	58	(8)
Cressy	14	(18)	32	(15)	50	(7)	67	(6)	69	(1)	86	(1)	91	(0)
Delegate	32	(36)	41	(30)	37	(22)	51	(24)	50	(2)	69	(5)	76	(6)
Young	22	(9)	30	(10)	34	(7)	48	(3)	60	(3)	77	(2)	84	(0)
Quirindi	27	(36)	29	(43)	30	(36)	31	(24)	34	(14)	60	(10)	63	(8)
Armidale	50	(33)	35	(33)	48	(29)	39	(25)	49	(12)	57	(9)	72	(5)

N supply effects on grazing potential
Across all locations crop N supply was found to be a key factor influencing the grazing potential of dual purpose wheat crops. Figure 2 shows an example of the simulated response of the 4 different phenology-types to available N at sowing at Hamilton, Victoria; similar responses are found at other locations. N availability had the largest effect on grazing potential of early sown winter wheat (Fig. 2). For example, on average a winter wheat cultivar sown in March could produce > 2000 DSE.days/ha when 150 kg N/ha was available at sowing, while this was reduced to 1300-1700 and 600-1200 DSE.days/ha when only 100 and 50 kg N/ha was available at sowing, respectively. The potential for greater N application to maximise early biomass production and therefore grazing from early-sown winter maturity types was observed across most locations. In later sowing dates and in spring cultivars the influence of N availability at sowing on grazing was less, with little or no increase in grazing obtained beyond 100 kg of N/ha at sowing.

Figure 2. Effect of sowing date and available nitrogen at sowing (hollow- 50kg N/ha; grey- 100kg N/ha; black-150kg N/ha) on grazing days (DSE.days/ha) from 4 wheat maturity types, winter-slow (i.e. Revenue) (a), winter-fast (i.e. EGA Wedgetail)(b), spring-slow (i.e. Gregory) (c) and (d) spring-fast (i.e. Lincoln) at Hamilton.



Conclusions
Based on the assumptions of this simulation analysis, we find significant opportunities to expand the use of wheat crops for both dual-purpose of grazing and grain production across Australia's HRZ including new environments such as south-west Western Australia and parts of the northern tablelands and slopes. Frequent early sowing opportunities and longer growing seasons in many of these areas make them suitable for longer season winter cultivars, which can provide large amounts of grazing for livestock and higher grain yields than traditional spring cultivars used in the lower rainfall systems. Nonetheless, the use of shorter winter cultivars and longer season spring cultivars could also open up new environments where dual-purpose use of crops can be practiced. Spring cultivars provided significantly less grazing opportunities (typically < 600 DSE grazing days/ha) and had lower yield potential by 1-3 t/ha compared to the early sown winter cultivars. Though the earlier-sown winter cultivars have a clear advantage in higher grazing potential (usually 2-3 times), the combined grazing and grain yield potential for mid-spring types in most areas are significant.

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