Yield responses to sowing date in southern NSW: one cultivar doesn't fit all

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Abstract
In southern NSW, wheat is traditionally sown in a window from early–late autumn (April–May), to ensure flowering occurs at an optimal time in spring. This project evaluated genotype (G) × environment (E) × management (M) interactions using a range of commercial cultivars and breeding lines that differed in phenology patterns from slow winter types through to fast spring types, where management relates to time of sowing. Field experiments were sown from early April–June at three locations in southern NSW from 2014–2018, where annual rainfall ranged from 224 to 808 mm. Significant interactions between G × E × M, with genotypic responses to sowing time varying across growing environments, and within seasons; largely attributed to seasonal water supply and demand and temperature extremes were determined. Four environment groups were identified, defined by site x sowing time, whereby genotype rankings differed; indicating cultivars are not broadly adapted to environment and management. This affirms that cultivar suitability varies with environment and grain yield can be optimised through management of sowing time by growers.

Key Words
Phasic development, G × E × M, frost, adaptation

Introduction
The adaptation and yield potential of wheat is dependent on matching phenology and sowing time of varieties to ensure flowering and grain formation occurs at an optimal time. In southern NSW, the optimal flowering period (OPF) is defined early, by the risk of reproductive frost damage, and later, by high temperatures and terminal water stress during grain filling (Flohr, Hunt, Kirkegaard, & Evans, 2017). Some faster developing cultivars are adapted to regions where frost and heat stresses occur in close proximity to each other (Lawes, Huth, & Hochman, 2016), whilst recent research has demonstrated that slower developing spring or winter cultivars are capable of increased water limited yield potential across a range of environments (Hunt, 2017). However, the longer phase duration of slower developing cultivars require earlier sowing dates to meet OFP and to maximise yield potential. Since the timing of stress on a crop can be influenced by phenology (genotype), the location and season (environment) and the time of sowing (management), the aim of this study was to investigate the interaction between G × E × M, to determine whether cultivar performance varies for specific environments, and whether this can be exploited by growers.

Methods
Field experiments
Field experiments were sown at three medium–low rainfall sites in southern NSW from 2014–2018, described in Table 1. At each site, a range of genotypes with varied phenology patterns, ranging from slow winter types to fast spring types were planted across sowing dates from early April to early June. The experiments were conducted as randomised split-plot designs (main plot: sowing date (SD); sub-plot: genotype) with three replications. If the seedbed was too dry to allow emergence at targeted sowing time, plots were irrigated with ~15–20 mm of water applied either using pressure compensating drip-line placed in seeding furrows to germinate seed and allow emergence (Wagga Wagga and Canowindra sites) or overhead sprinklers via lateral move (Condobolin site). Targeted sowing dates were 20 April, 5 May and 25 May, with an additional early sowing time (5 April) planted at the Wagga Wagga site 2017 and 2018. All sites were sown within 7 days of the target dates. Target plant densities, fertiliser and all other crop management were

implemented according to local district practice. At each site grain yield was attained via machine harvest of the plots.

Table 1. Description of field experiments, annual rainfall, growing season rainfall (GSR) (Apr–Oct) and frequency of frost events (<2°C) and heat events (>30°C) during growing season (Apr–Oct) from 2014–2018.

Site	Year	Annual rainfall (mm)	GSR(Apr–Oct) (mm)	Frost events (Apr–Oct)	Heat events (Apr–Oct)
Wagga Wagga, NSW	2014	478	282	45	11
	2015	648	379	44	7
	2016	779	592	14	3
	2017	445	230	92	0
	2018	409	174	44	12
Condobolin, NSW	2014	460	167	35	17
	2015	454	264	39	21
	2016	698	498	24	4
	2017	490	151	78	8
	2018	224	91	44	18
Canowindra, NSW	2014	669	307	63	9
	2015	581	305	64	11
	2016	808	631	28	4
	2017	525	162	70	2
	2018	467	212	63	16

Statistical analysis

A multi-environment trial (MET) analysis using the linear mixed models approach of (Smith, Cullis, & Thompson, 2001) was implemented for all experiments on grain yield (t/ha). This methodology captures the genotype x environment (G × E) interaction using factor analytic models. Sowing date, site and year were concatenated into an environment term and best linear unbiased predictors (BLUPs) (Piepho, 1998; Robinson, 1991) were generated for each G × E combination.

Results and Discussion

Grain yields varied significantly between sites, year and SD, and we identified four distinct groups (clusters), whereby genotype rankings differed significantly between the environments (Figure 1).

Cluster 1

Grain yields in Cluster 1 ranged from 1.07–4.27 t/ha, with a median yield of 2.20 t/ha. Cluster 1 comprised of sowing dates from 5–20 April at the Canowindra (2015, 2017) and Wagga Wagga (2014, 2017, 2018) sites. There was an influence of frost on the genotype rankings in these seasons. The best performing cultivars were generally winter types e.g. Manning, LRPB Kittyhawk, which are best adapted to earlier sowing due to their extended vegetative phases, whilst the lowest ranking cultivars were fast spring types e.g. Corack and LRPB Spitfire, which flowered earlier than the OFP from these sowing dates.

Cluster 2

Cluster 2 was the highest yielding group, ranging from 3.58–6.51t/ha with a median grain yield of 4.89 t/ha. Site, year and SD varied within Cluster 2, comprising of a combination of early-May sowing dates for Canowindra (2015, 2016), mid-April (2015, 2016) and late-May (2017) at Wagga Wagga and April–May sowing dates at Condobolin in 2016. Winter or slow spring types such as EGA Wedgetail, LRPB Trojan and Beckom were among the highest ranked genotypes, and had relatively stable grain yield across a range of sowing dates in these seasons, whilst fast spring types e.g. LRPB Spitfire and Emu Rock recorded the lowest yields.

Cluster 3

The lowest median grain yield was recorded in Cluster 3 (1.73 t/ha), with yields ranging from 1.18–2.16 t/ha. Cluster 3 consisted of mid-April to early-May sowing dates for the Canowindra (2017), Wagga Wagga (2017, 2018) and Condobolin sites (2014, 2015, 2017, 2018) as well as a late-May sowing at Condobolin in 2017. These sites and years were characterised as having a high incidence of frost events at the three sites, and recorded the lowest GSR (Table 1). The highest ranking genotypes were mid-slow spring types, including Coolah, EGA Eaglehawk and Sunvale, whilst faster spring types such as Emu Rock, Corack and Condo recorded the lowest yields.

Cluster 4

Grain yields ranged from 1.79–3.06 t/ha in Cluster 4, with a median grain yield of 2.51 t/ha. As with Cluster 2, there was variation in the site, year and SD combinations in Cluster 4, ranging from late-May sowing dates at the Canowindra site (2015, 2017), early–late May at the Wagga Wagga site (2014, 2015, 2018) and across SD from late-April to early-June at the Condobolin site (2014, 2015, 2016, 2018). In contrast with the other cluster groupings, the best performing cultivars in Cluster 4 were fast spring types, such as Scepter, Corack and Mace, whilst winter types such as Manning and EGA Wedgetail were among the lowest ranking genotypes.

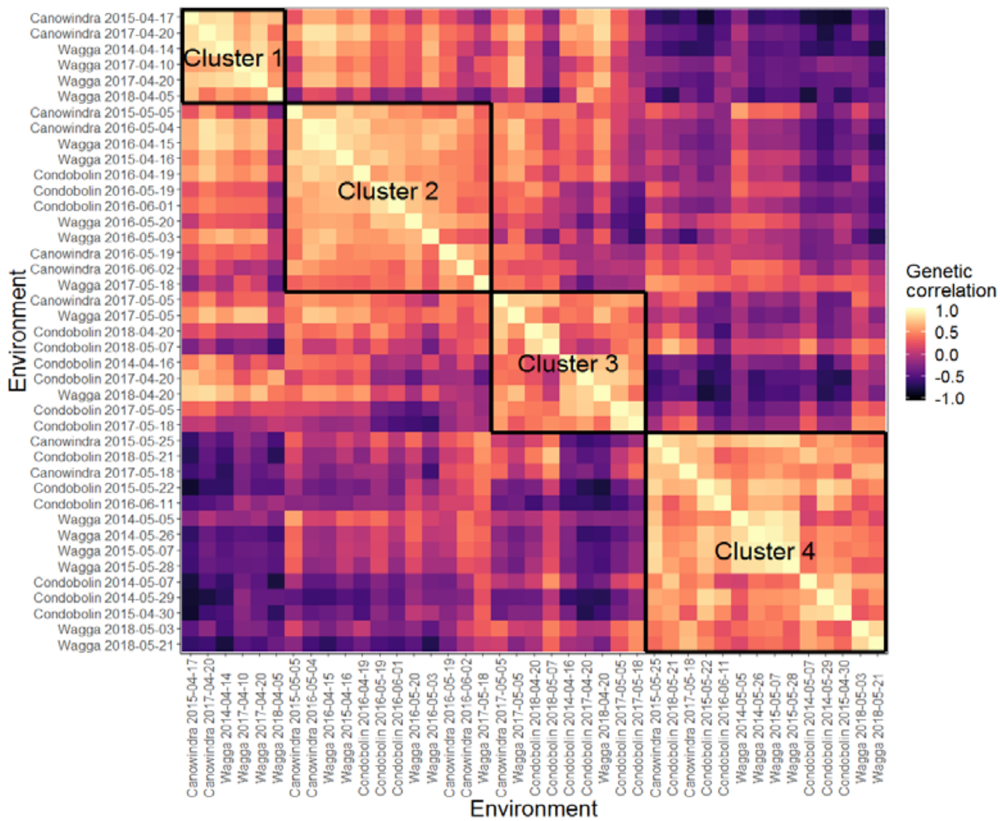

Figure 1: Genetic correlations between each pairwise combination of environments (location x sowing date) are shown by the shading for experiments conducted between 2014–2018 at Wagga Wagga, Condobolin and Canowindra. A genetic correlation of one implies perfect concurrence of genotype rankings between two environments; zero implies that there is relationship in genotype rankings between two environments and a genetic correlation of minus one indicates a complete reversal in genotype rankings from best to worst between two environments.

These data provided a wide range of environments where predicted yields varied from 1.07–6.51 t/ha, and provided evidence that there are significant G × E × M interactions on grain yield responses in southern NSW. Sites changed within cluster groupings with season. For example, the Condobolin site was in the highest yielding group (Cluster 2) for all sowing dates in the 2016 season, whilst was in the lowest yielding group (Cluster 3) in other year × SD combinations. This suggests that seasonal variation in growing season rainfall, as well as temperature extremes imposed on the crop, which could be altered by SD, were the main driver of environment, rather than geographic location or soil type.

There was evidence to suggest that early sowing of slower developing genotypes resulted in higher yield potential than later sowing of faster developing genotypes as described by Hunt (2017). Whilst some genotypes were capable of relatively stable grain yields across some cluster groups (Figure 2), there was a complete reversal in genotype rankings from Cluster 1 to 4 (Figure 1, Figure 2), whereby genotypes moved from highest to lowest yielding based on environment (site, year, SD). The implication of these findings is that there are no commercially available genotypes that are broadly adapted across a wide range of growing environments in southern NSW.

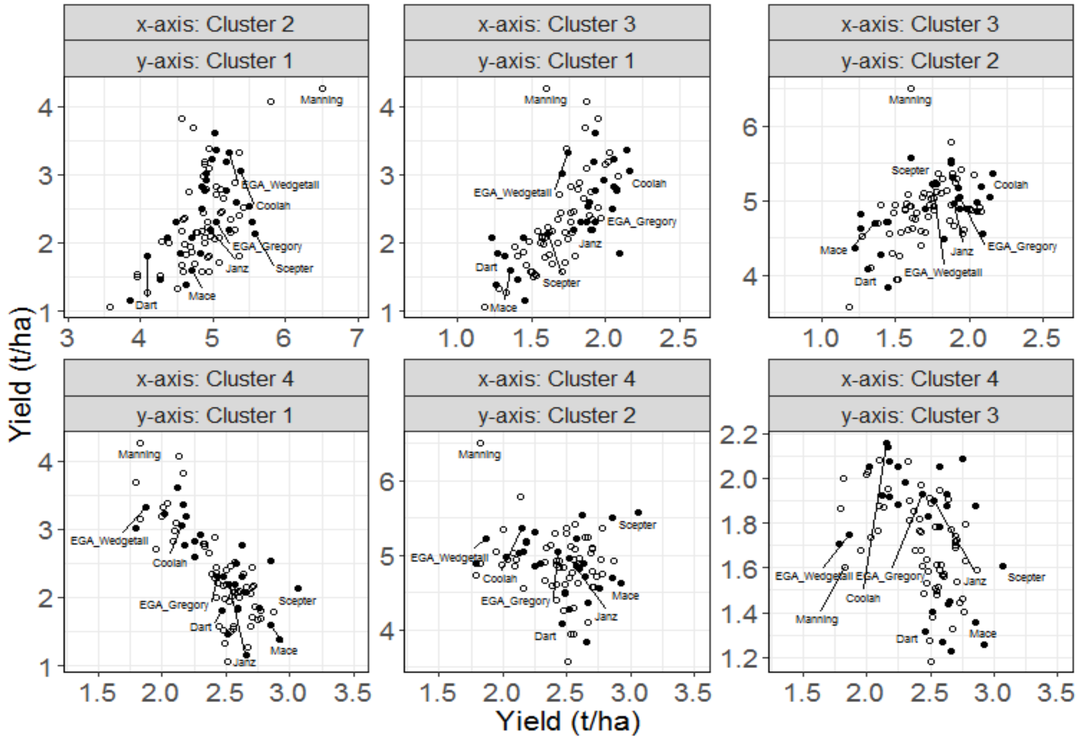

Figure 2. Pairs plot of genetic predictions (BLUPs) averaged across environments within the same cluster. The open circles denote genotypes that were present in less than 50% of trials and the closed circles denote genotype that were present at more than 50% of trials.

Conclusion

There were significant interactions between G × E × M, whereby genotypic responses to sowing date varied across sites in southern NSW, and within seasons for cultivars with varied phenology patterns. These findings indicate that the cultivars tested are not broadly adapted to environment or management, and as such there is scope for growers to optimise grain yield through cultivar selection, and management of sowing date by considering phenology responses.

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