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Commercially available wheat cultivars are broadly adapted to location and time of sowing in Australia's grain zone

R.A. Lawes[a,*], N.D. Huth[b], Z. Hochman[c]

[a] CSIRO Agriculture, 147 Underwood Avenue, Floreat, WA 6014, Australia
[b] CSIRO Agriculture, PO Box 2583, Brisbane, Qld 4001, Australia
[c] CSIRO Agriculture, 203 Tor St, Toowoomba, Qld 4350, Australia

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ABSTRACT

Farmers must choose which cultivar to grow based on the phenology of the cultivar and anticipated season length. The current study investigated the established doctrine of sowing fast maturing cultivars late, and slow maturing cultivars early. This was explored by quantifying the genotype (G) × environment (E) × management (M) available to farmers using commercially released cultivars, where management relates to the time of sowing. Nineteen cultivars of spring wheat (*Triticum aestivum*) were sown at 3 times of sowing (early, conventional and late) at 13 sites in 2011 and 2012. Sites were located throughout the Australian grain growing region in Queensland, New South Wales, Victoria, South Australia and Western Australia from latitudes 27°34′S to 35°09′S where annual rainfall ranged from 237 mm to 747 mm. In general, the three way interaction between G, E and M for yield was small and cultivar could not overcome the yield penalty associated with a late time of sowing. At 11 of the 13 sites, fast to moderately fast maturing cultivars sown early generated the highest yields. Fast maturing cultivars sown late could not compensate for a late time of sowing. Commercial cultivars were broadly adapted to environment and management, and with these cultivars, the Australian grain growing region could be split into just two environments, south and north. Even then, season appears to be the main arbiter of environment, rather than location *per se* as individual sites moved from one group to the other, depending on season. There was no evidence to suggest farmers could exploit a cultivar by management interaction for time of sowing with commercial cultivars, as the outcome of the season is unpredictable, and with current technology farmers should simply choose the best performing cultivar for their region and sow it as early as possible.

1. Introduction

The goal of plant breeders is to produce new cultivars that are better adapted to a targeted production environment than their predecessors and to release these cultivars for commercial use by farmers. The farmer must then choose a cultivar for their particular environment and sow it at a particular time. The time of sowing immediately introduces a management component into the choice of cultivar. These objectives, enunciated by Comstock (1977) and discussed by Chapman (2008) highlight the importance of breeding cultivars for a particular environment, and the response of the cultivar in a particular environment can be further influenced by management. Therefore the farmer and the breeder must consider genotype (G), environment (E), management (M) and the interactions of those components.

Agronomists and plant breeders are both conscious of environment, but the two disciplines have evolved differently. For an agronomist, the environment has historically been defined in terms of the stresses applied to a plant through its life. These may include water stress (Nix and Fitzpatrick, 1969), nutrient stress, and temperature stress (Asseng et al., 2011). The importance of these stresses are summarised by frameworks such as those described by (Passioura and Angus, 2010), who highlight the importance of matching the phasic development of the plant to the water supply and temperature stresses of a particular region.

For breeders, the definition of environment may be defined statistically, where cultivars will be grown across a wide range of environments (Cooper and Delacy, 1994). The variance components from an analysis of variance may be employed to determine the extent of variation in a trait that can be attributed to cultivar, the environment and the cultivar by environment interaction. Since large numbers of cultivars are often screened, statistical techniques have evolved to group cultivars into those that may be broadly adapted to an environment or specifically adapted to

* Corresponding author.
E-mail address: roger.lawes@csiro.au (R.A. Lawes).

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Table 1
Cultivars and the number of plots of each cultivar sown at each site.

Maturity	State	Queensland		New South Wales		Victoria	South Australia				Western Australia			
	Location	Bungunya	Nangwee	Spring Ridge	Temora	Walpeup	Minnipa		Turretfield		Corrigin		Eradu	
	Year	2012	2012	2011	2011	2011	2011	2012	2011	2012	2011	2012	2011	2012
Fast	Axe				3	9	9	9	9	9				
	Westonia										9	9	9	9
	Lincoln				6									
	Livingston	9	9	9	9									
	Wyalkatchem					3	6	6	6	6	9	9	9	9
Fast–Moderate	Crusader	9	9	9	6									
	Carnamah										6	6	6	6
	Gladius	3	3	3	6	9	9	9	9	9	3	3	3	3
	Yitpi					6	6		6		3		3	
	Scout							6		6		3		3
	Janz	6	6	6	6	6	6	6	6	6	6	6	6	6
Moderate	Derrimut					9								
	Correll					6	9	9	9	9				
	Magenta					3	3	3	6	6	9	9	9	9
	Lang	9	8[a]	9										
	Gregory	9	9	9	9	3	6	6	3	3	3	3	3	3
Slow	Wylie	9	9	9										
	Endure										6	6	6	6
	Bolac				9									

[a] Missing plot TOS 1.

an environment. Therefore, concepts such as the regression on the environment mean (Finlay and Wilkinson, 1963), and various multivariate techniques have been employed to detect G × E interactions (Cooper and Delacy, 1994). The analysis of multi-environment trials has evolved and is now quite flexible (Smith et al., 2005). For example, the nuances of individual trials can be accommodated where some sites may have strong spatial processes that need to be statistically modelled. Assumptions about the covariance structure of cultivars and environment at particular locations can also be explored using either compound symmetry, diagonal or factor analytic models (Smith et al., 2001). On occasions, environmental covariates such as rainfall can be introduced into such a model to further define environment (Eagles et al., 2010).

The attempt to define cultivar performance for specific environments is partly driven by the need to communicate to farmers which cultivars will be suited to their farm. Furthermore, seasonal conditions and logistics may influence management decisions such as the time of sowing, where conventional wisdom suggests longer season cultivars should be sown early, and shorter season cultivars should be sown later. Some fast maturing cultivars are adapted to regions where the cold and heat stresses occur in close temporal proximity to each other. Slower maturing cultivars have been developed for environments with higher rainfall, where there is an opportunity for the plant to remain in the vegetative stage longer, produce more biomass, produce a higher number of grains, spend longer during grain fill and produce grains of equivalent kernel weight to the shorter season cultivar (Richards et al., 2014). Therefore the farmer and the plant breeder are trying to grow a crop where the timing and duration of vegetative and reproductive growth are optimised to use all the available resources on offer and avoid temperature stress. Unfortunately, the water deficit patterns and extent of the stresses all vary with season and location (Chenu et al., 2011), and this complicates the development of cultivars for niche environments and management actions.

Since the timing of stress on a crop can be influenced by phenology (cultivar), the location and season (environment) and the time of sowing (management), the interaction between G × E × M may be important to farmers. The three way interactions are increasingly being examined for factors such as tillage practice (Rebetzke et al., 2014), organic and conventional systems (Kamran et al., 2014) and weed management (Lemerle et al., 2001). Many of these earlier studies evaluated genetic material that had yet to be released to the industry, and these earlier studies were all attempting to identify whether G × E × M existed and should become part of the breeding process.

Our goal here is to evaluate the G × E × M concept as it applies to farmers with regard to time of sowing using current, commercially available cultivars of varying maturity. To that end, the performance of 19 elite commercially available wheat cultivars of varying phenology sown at 3 different times in 13 locations across the entire Australian grain growing region were evaluated. Trials were located in Western Australia, South Australia, Victoria, New South Wales and Queensland. These data are used to determine whether farmers should change cultivars, given the time of sowing, where long season cultivars should be sown early and shorter season cultivars sown later. The current study quantifies the extent of the genetic variation available to farmers, and also considers whether niche environments exist across the Australian continent that farmers can realistically exploit with currently available genetic material.

2. Materials and methods

Nineteen cultivars of spring wheat (*Triticum aestivum*) were chosen and selected in consultation with plant breeders to ensure cultivars were suited to a particular location, thus by definition, not all cultivars were grown at each location. Cultivars with maturities varying from early through to late were grown at each location (Table 1). At every location cultivars were sown at three times of sowing (TOS), early (late April to early May; TOS 1), conventional time of sowing (mid May to early June; TOS 2) and late (late June to early July; TOS 3). Specific times of sowing at each location are presented in Table 2.

Sites were managed so that nutrients were non-limiting. Fertiliser was applied at sowing using formulations of S, K, and trace elements appropriate to the region and the soil type. If the season was favourable and soil fertility was considered limiting, additional N was applied to ensure the crops could achieve their highest possible yield potential as assessed in August. At each site total N applied is presented in Table 3. The sites had various soil types ranging from black vertosols of heavy texture at Nangwee in Queens-