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Dry sowing increases farm level wheat yields but not production risks in a Mediterranean environment

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ABSTRACT

Dry sowing is the practice of sowing a crop into a dry seed bed before the autumn rains. This is in contrast with the traditional practice of wet sowing where seed is placed into a moist seed bed following a rainfall event in autumn. We evaluated the putative benefits and risks of dry sowing for different soils and locations in Western Australia (WA) using a multi-field (15 or 30 day sowing programmes), multi-year (54 seasons) simulation model analysis with the Agricultural Production Systems Simulator. Importantly our analysis evaluated dry sowing at the farm rather than the field level. Dry sowing has increased in WA, in response to reduced rainfall, increased variation in the timing and amount of autumn rainfall and increased farm areas. Dry sowing is considered beneficial because it can increase yields, make better use of available machinery/labour and decrease heat stress during grain filling due to earlier flowering. Perceived risks of dry sowing include early season water deficit and frost around anthesis. There were large potential yield benefits of up to 35% with dry sowing compared to wet sowing. The largest yield benefits were for heavy soils, drier locations, and larger cropping programmes. Yield gains were greatest in seasons with low to medium yield potential (300–2500 kg/ha). In seasons with a late start to the opening rains dry sowing brought the sowing date of the last field sown earlier compared with wet sown programmes, with a clear yield benefit for early sowing. Dry sowing also allowed larger farm areas to be sown consistently with equivalent machinery capacity and labour availability. The results highlighted that growing-season (May–Oct) rainfall still set the upper limit to yield but that by practicing dry sowing farms are more likely to yield close to the water-limited benchmark. Dry sown farms produced an average of 350 kg/ha less than the water-limited benchmark and the wet sown cropping programmes 960 kg/ha less. At most sites the risks of a soil water deficit during seedling establishment more than doubled in a dry sown cropping programme compared with wet sowing. Dry sowing resulted in a very small increase (maximum 4%) in the proportion of crop frosted at anthesis. In contrast, dry sowing markedly reduced the proportion of crop that was exposed to heat events during grain filling. The analysis has demonstrated that single field simulation models can be used to evaluate management strategies applied at the individual field level but that influence whole farm productivity. Dry sowing is an appropriate strategy to manage yield risk by increasing grain yields with a minimal increase of production risks.

1. Introduction

Traditional agronomic research has focussed on management strategies that maximise productivity and minimise risk in individual fields. However, farmers manage fields as part of a whole farm with resource limitations, such as time, labour, and machinery capacity that constrain the management of individual fields. These constraints mean that each field cannot be managed optimally and the result of a practice quantified for an individual field may not represent the aggregate result expressed across a whole-farm. Two examples are the allocation of limited irrigation water across a farm (e.g. Power et al., 2011) or a limited capacity to sow crops in a timely manner. The latter is the focus of this paper.

Simulation models can be used to examine the effect that management has on yield and risk. Recent model improvements allow users to develop multipoint simulation structures that examine the interactions between various fields within a farm and the implications for farm performance (Holzworth and Huth, 2004; Power et al., 2011; Rodriguez et al., 2011). In this paper we demonstrate how a crop simulation modelling platform (Agricultural Production Systems Simulator, APSIM; Holzworth et al., 2014) can be used to place a detailed understanding of the effect of sowing date on

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crop production, into the context of a whole farm in Western Australia (WA). Dry sowing is the practice of placing seed into dry top soil before the first autumn rains and is an increasingly important practice in WA (Celenza et al., 2013). Dry sowing allows a greater proportion of crops on a farm to be sown early in the season.

In Mediterranean environments, such as the wheat belt of WA, the cropping season is defined by the onset, amount and duration of rainfall. Growing-season rainfall (May–Oct) sets the yield potential (French and Schultz, 1984) and agronomic practices are aimed at maximising the efficiency with which growing-season rainfall is used (Turner, 2011). Early sowing is vital to maximising wheat yield and quality (Sharma and Anderson, 2004; Turner, 2011). Farm scale machinery and labour constraints mean that the earlier sowing of one field brings the sowing date of subsequent fields earlier, with a compounding yield benefit across the farm. In WA farms have traditionally waited for the first autumn rains to commence sowing (wet sowing). As farm area increases the time required to complete sowing also increases. Dry sowing can to some extent buffer this effect by allowing an earlier start to sowing programmes.

An increased risk of yield-damaging frosts occurring during anthesis and an increased risk of lethal water deficits occurring during seedling establishment (Turner, 2011) are two perceived risks of dry sowing. With dry sowing much of the crop area germinates on the first autumn rain and therefore flowering is on average earlier and more condensed than with wet sowing. With more crop area flowering early, a dry sown programme is exposed to an increased risk of frost damage during anthesis. Dry sowing may also increase the incidence of soil water deficits during crop establishment due to small rainfall events that trigger germination with very little follow-up rain. A benefit of dry sowing is the potential reduction in heat stress during grain filling. In WA as grain filling progresses through late spring there is a substantial increase in the risk of high temperatures ($T_{max} > 35$ °C) (Asseng et al., 2011) that can have catastrophic effects on wheat yield (Talukder et al., 2014) and quality (Stone and Nicolas, 1995). Grain filling will occur earlier in a dry sown farm with a reduced risk of heat stress.

The impacts of dry sowing are important at the farm rather than the field scale and therefore there has been little published experimentation. In order to evaluate the benefits and risks of dry sowing, a farm-level analysis is necessary. This paper presents a modelling approach linking the management and subsequent growth of individual crops into a whole farm context. We quantify the benefits and risks of dry sowing across seven sites in WA varying in rainfall and temperature.

2. Methods

The analysis focuses on understanding the impact on farm production and risk, from the dual constraints of environment (rainfall, frost etc.) and capacity to complete the task at hand (labour/machinery availability). The analysis deals with a critical period in the farming calendar when there is only a single task and focuses on the dominant management constraint, labour and machinery, to sow the crop area within a short window defined by soil moisture availability. Hence we configured APSIM to simulate a set of fields sown in sequence that approximates a typical farm. The analysis by necessity omits the sowing of minor crops and other soil types. A multi-field, multi-year simulation model analysis in the APSIM framework (Holzworth et al., 2014) was used. The APSIM wheat model has been validated across WA (Asseng et al., 1998; Oliver and Robertson, 2009; Oliver et al., 2009) and was considered appropriate for these simulations.

Simulations were run for seven representative locations across the WA wheat belt for 54 seasons (1957–2010). The locations were all water-limited with growing season (May–October) evaporation exceeding rainfall (Table 1). The locations were Merredin from the low rainfall zone (<325 mm annual rainfall), Cunderdin, Dalwallinu, Mingenew, Mullewa and Salmon Gums from the medium rainfall zone (325–450 mm annual rainfall) and Katanning from high rainfall zone (450–750 mm annual rainfall) (Fig. 1). The sites also covered a range from the north to the south of the WA wheat belt (Fig. 1) with a range in the timing and incidence of both frost and heat stress events (Table 1). Weather data for each site were obtained from the SILO website (Jeffrey et al., 2001, www.longpaddock.qld.gov.au/silo/).

For each location, simulations were run for 16 farm management scenarios made up of two ratios of sowing capacity to farm size (15 or 30 day sowing programmes), two soil types (heavy and light), and four maximum limits to the area of dry sowing (0, 33, 66 and 100% of total farm area). The lengths of these sowing programmes represent farms with a range of different sowing capacities and cropped areas and are broadly representative of the range found on-farm in WA. The two soil types were the 'Sand' (hereafter referred to as 'light soil') and 'Shallow loamy duplex' (hereafter referred to as 'heavy soil') described by Oliver and Robertson (2009). In the top 200 mm of soil the plant available water holding capacity (PAWC) is 10.9 and 17.4 mm, respectively. The PAWC is the field capacity (drained upper limit) less the permanent wilting point (crop lower limit) and thus reflects the total amount of water that the soil can potentially hold (Dalgliesh and Foale, 1998). The PAWC was low and typical of soils in this region. Across the entire soil profile the PAWC was 98 for the light soil (to 2.5 m depth) and 67 mm for the heavy soil (to 1.5 m soil depth). The actual simulated crop rooting depth was generally much shallower than this depending on season.

2.1. Multi-field simulations

The analysis was restricted to wheat with each farm having a single soil type. Thus, the interactions between crop and soil types were not explored. A series of rules subject to various environmental and management constraints were applied at the farm level to determine the sowing dates of individual fields using the 'Manager2' module. The yield outcomes for each field were then aggregated to

Table 1
Mean annual rainfall, growing-season (May–October) rainfall, growing-season evaporation, frost events and heat stress events for the seven sites used in the study. Data are the means across the 54 years (1957–2010) of the simulations.

Site	Annual rainfall (mm)	Growing-season rainfall (mm)	Growing-season pan evaporation (mm)	Frost events ($T_{min} \leq 0$ °C)				Heat stress events ($T_{max} \geq 35$ °C)		
				Jul	Aug	Sep	Oct	Sep	Oct	Nov
Mullewa	333	239	762	0.1	0	0	0	0	1.7	5.7
Mingenew	387	306	730	0	0	0	0	0	1.2	4.7
Dalwallinu	358	255	655	0	0	0	0	0	0.7	4.3
Cunderdin	360	265	570	0.4	0.4	0.2	0	0	0.6	3.6
Merredin	324	216	597	1.4	1.5	0.5	0	0	0.4	3.2
Katanning	475	348	429	0.7	0.3	0.1	0	0	0	1.2
Salmon Gums	356	207	541	2.2	2.1	1.0	1.0	0	0.5	2.2