PART V – MANAGING THE SYSTEM

Farming systems research site, Wagga Wagga NSW (Courtesy: John Kirkegaard and Graeme Sandral)

Establishing the cotton crop (Courtesy: Rose Brodrick)

Furrow irrigation of cotton (Courtesy: Rose Brodrick)

Chapter 18

Evolution of early sowing systems in Southern Australia

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Introduction

Historical advances in water-limited yield in drought-prone environments of southern Australia have been achieved by adapting crop phenology to environment, to ensure that crop establishment occurs following autumn breaking rains (April-May) and flowering occurs in an optimal period in spring after frost risk but before heat stress and terminal drought (Richards 1991). (The autumn break is the first rainfall of sufficient volume to ensure successful germination and establishment and represents the start of the growing season). This historical phenological adaptation included the release of Australia's first adapted spring wheat cultivar 'Federation' by Farrer in 1901, the release of photoperiod insensitive semi-dwarf wheat cultivars in the 1970s, and the adoption of conservation agriculture in the 1980s which supported earlier sowing of wheat and other dominant crops (Fischer 2009).

In the last 20 years, the average farm size has doubled in most cropping zones of Australia (Anderson *et al.* 2016). The widespread adoption of NT, reduced livestock numbers and a wide selection of herbicides have supported a shift towards greater farm size, intensification of cropping programs and associated earlier sowing (D'Emden *et al.* 2008, Fletcher *et al.* 2016). These have been important shifts to achieve economies of scale. Dry sowing is the technique of sowing crops into dry soil before the breaking season rains to enable a larger area of crop to germinate as soon as the germinating rain arrives. To avoid confusion, the term 'early sowing' refers to the date on which physical sowing occurs, either into a dry or moist seed bed. The term 'establishment date' refers to the date on which seed becomes imbibed and germination begins either by planting in a moist seed bed, or the date on which dry sown seed receives germinating rainfall. Early sowing here is also defined as prior to 1 May.

Between 1978 and 2015, national wheat sowing dates have moved earlier by 1 to 1.5 days per year (Figure 1, Stephens and Lyons 1998, Fletcher *et al.* 2016, Flohr *et al.* 2018b), with similar shifts for canola (Kirkegaard *et al.* 2016) and barley also likely. The traditional sowing window of mid-May to June has shifted to a mean sowing date of ~10 May (Figure 1, Flohr *et al.* 2018b). Today, approximately 50% of growers dry sow a proportion of their crop area, which has improved machinery and labour efficiencies (Fletcher *et al.* 2016). While earlier sowing has logistical benefits, advancing mean flowering time closer to the environmental optima has been key to maintaining national yields under seasons characterised by reduced rainfall, warmer springs and more rapid onset of drought (Pook *et al.* 2009, Kirkegaard and Hunt 2010). Canola yield declines 5-12% per week of delay in establishment after mid-April in Australia (Farre *et al.* 2002, Kirkegaard *et al.* 2016) while in wheat, a decline of up to 1-7% yield per week delay past the optimal establishment time has been found in SA, NSW and WA (Kohn and Sorrier 1970, Coventry *et al.* 1993, Sharma *et al.* 2008, Lawes *et al.* 2016). Early crop establishment and longer growth durations achieve greater efficiency in converting rainfall into grain primarily through deeper root growth and access to water (Kirkegaard *et al.* 2015), reduced evaporative losses from the soil (Passioura and Angus 2010) and increased transpiration efficiency (Kemanian *et al.* 2005).

In this chapter we discuss how and why early and dry sowing systems have evolved in Australia, how they have been successfully implemented and the challenges and opportunities that remain. We also use two grower case studies to demonstrate how early sowing is currently implemented on-farm.

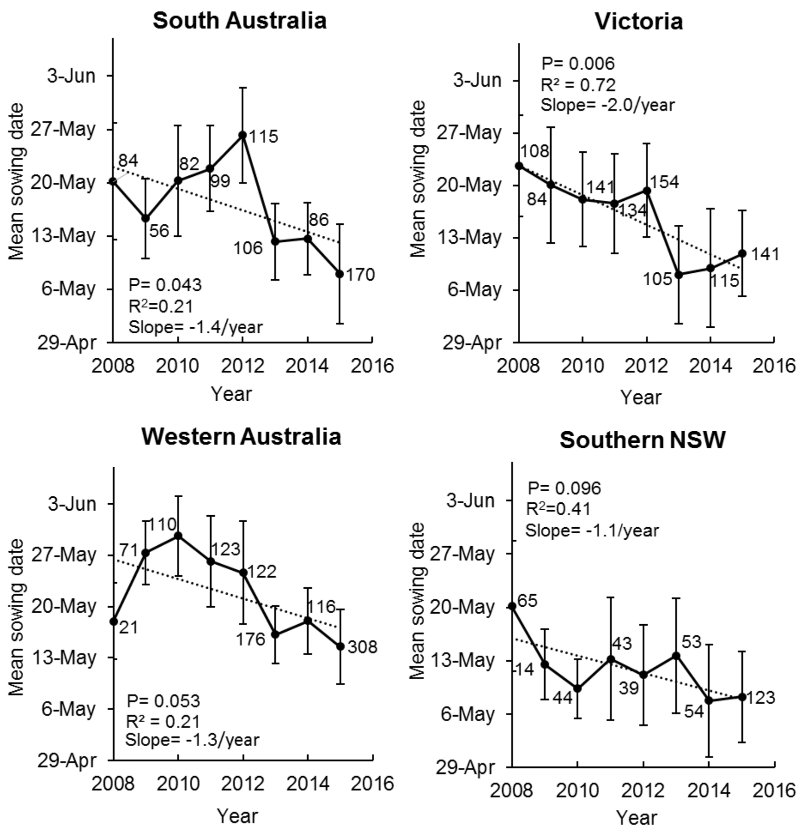

Figure 1. Mean sowing date for different regions from 2008-2015 from the Yield Prophet® data base. The number next to marker is the number of fields included in the mean sowing date for each year. Error bars are the standard deviation around the mean (extracted from Flohr *et al.* 2018b)

Crop type and cultivars for early sowing

In southern Australia, an optimal flowering period (OFP) exists whereby grain yield is maximised, and the combined risk of frost, drought and heat stress are minimised (Farré *et al.* 2004, Flohr *et al.* 2017, Lilley *et al.* 2019). This period is important as grain number in cereals is determined just prior to, and at, flowering (Fischer 1985). The optimum temperature to facilitate pollination and fertilisation in wheat is in the range 18-24°C, with a minimum of 9°C and maximum of 31°C (Porter and Gawith 1999). In canola, grain yield is most sensitive to stress between 100 and 500°C.days (Kirkegaard *et al.* 2018) after the start of flowering, and air temperatures above 29.5ºC during flowering can result in floral sterility and grain number reduction (Angadi *et al.* 2000, Morrison and Stewart 2002, Harker *et al.* 2012).

Flohr *et al.* (2017) defined OFPs as the period that minimises the combined effect of frost, heat, water stress and optimises radiation capture for wheat yield for several environments across the south-eastern Australian wheat belt using the Agricultural Production Systems SIMulator (APSIM, Holzworth *et al*. 2014) and historical climate records. Lilley *et al.* (2019) presented a similar study in canola. Both simulation studies found that the OFP varied with environment; the relative importance of seasonal water supply and demand and extremes of temperature varied in the defining windows. Consequently, sowing date recommendations vary for cultivars and crop types with different phenology patterns to optimise these physiological trade-offs under varied climatic conditions, and across growing environments (Matthews *et al.* 2019). By sowing early and growing cultivars with appropriate phenology to match the OFP, Hunt *et al.* (2019) demonstrated that national average wheat yields can be increased by 0.54 t/ha. Availability of a greater range of cultivars that cover a broader range of sowing dates yet flower at the optimum time would increase flexibility and enhance management options available to growers (Fischer 2011).

Wheat cultivars can be broadly classified into two main types distinguished by their response to vernalisation, and their adaptation to different sowing dates; these are referred hereafter as either winter or spring types. Winter types have an obligate vernalisation requirement, meaning they must experience a period of vernalising (cold) temperatures prior to developmental progression from vegetative to reproductive phase (Hunt 2017). Acceleration of development in winter types occurs when exposed to temperatures in the range of -2 to 15°C, with an optimum of 5°C (Ewert *et al.* 2002). In contrast, spring types generally do not require vernalisation to progress developmentally, though can vary in their responses, whereby exposure to vernalising temperatures can hasten their development (facultative vernalisation requirement), or have no effect on development (vernalisation insensitive) (Pugsley 1983, Hunt 2017). Vernalisation and photoperiod (day length) sensitivity interact and as such there is genotypic variation among winter and spring types in their flowering responses across environments (Davidson *et al.* 1985, Eagles *et al.* 2010).

In wheat and barley, yield improvements have been achieved by direct selection for yield based on traditional May sowing dates and an appropriate flowering time, as such cultivars with a spring development pattern dominate southern Australian farming systems (Flohr *et al.* 2017, Porker *et al.* 2017). The early-May sowing dates reported in Figure 2 are optimal for existing mid-fast spring wheat, although if sown too early they may flower outside the OFP, and suffer yield reductions due to frost damage and/or insufficient biomass accumulation. Consequently, winter or slow spring cultivars are required to align better with earlier sowing dates and with the OFP (Figure 2, Porker *et al.* 2017, Flohr *et al.* 2018b).

While dry and early sowing are complementary practices, the dry sowing of slow developing cultivars is not a suitable strategy in all environments, unless seed is sown deep into stored soil moisture to promote establishment at sowing or rainfall is forecast soon after sowing and prior to the recommended sowing date of fast developing cultivars (Asseng *et al.* 2016). This applies particularly to Mediterranean type environments, where average growing seasons tend to be warmer. In these environments vernalisation requirements of winter wheat cultivars are met too late in the season for late emerging crops, which delays flowering and exposes crops to more heat and water stress risk. The yield under these circumstances is less than that of fast developing cultivars sown later.

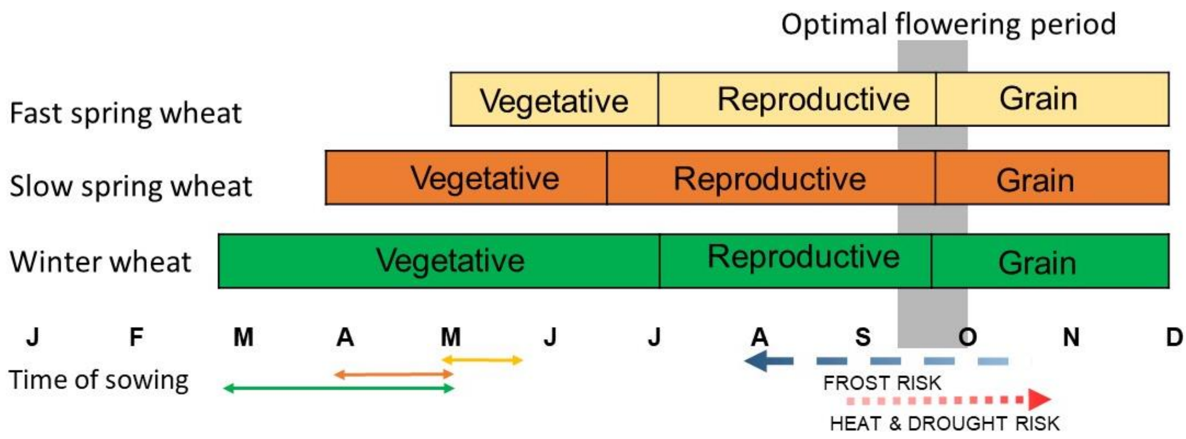

Figure 2. Duration and timing of the different development phases of winter wheat and fast and slow developing spring wheats. Optimal sowing windows are represented by arrows colour coded to the wheat type and the risks of frost and heat/drought are indicated by broken arrows and colour gradients. The grey band represents the OFP which minimises the combined risks from frost and heat/drought (Adapted from Hunt 2017)

Recent trends in earlier sowing, greater areas of dual-purpose cereals, and research highlighting whole-farm benefits of winter cultivars (Hunt *et al.* 2019) has led to an increased demand for adapted winter types (Hunt 2017). Whilst breeders have responded with the release of five new winter wheats in the period 2013-2019 (Porker *et al.* 2019), there has been limited selection within breeding programs for winter barley cultivars. There is currently only one winter barley cultivar suitable for early sowing, cv Urambie, which was released in 2005 (Porker *et al.* 2017). Breeding traits other than phenology have also been identified as beneficial for early sowing and successful establishment. These include increased coleoptile length and early vigour (Kirkegaard and Hunt 2010, Rebetzke *et al.* 2016, Zhao *et al.* 2019) which could also contribute to increased early biomass available for grazing in dual-purpose systems (Harris *et al.* 2017).

Similar to cereals, earlier sowing of canola can improve productivity and reduce the risks associated with canola production, provided appropriate phenology is used to match the OFP (Kirkegaard *et al.* 2016, Lilley *et al.* 2019). Improved understanding of cultivar phenology (Whish *et al.* 2018, Brill *et al.* 2019) and improved agronomic management has prompted a re-evaluation of sowing date recommendations in canola (Kirkegaard *et al.* 2016, Lilley *et al.* 2019) with sowing windows shifting three weeks earlier than previously recommended. Currently there is a range of spring canola varieties with mid to fast phenology, and very slow phenology winter canola varieties used for grazing in the high rainfall zone, but few commercial varieties with 'fast winter' phenology driven by vernalisation (Kirkegaard *et al*. 2016). The potential benefits of these varieties are predicted to be significant for both grain yield and dual-purpose use (Christy *et al.* 2013, Lilley *et al.* 2015) and breeding companies have started to investigate winter-spring crosses and 'semi-vern' canola types to fill this phenology gap in Australian canola germplasm.

Crop management with early sowing

Aside from choosing the correct cultivar for early sowing to align with the OFP, there are several other important management considerations in early/dry sowing. In a 2019 survey using Twitter, 41% of growers in south-east and south-west Australia (n=535) rated managing the weed burden as their primary management concern when early and dry sowing (Figure 3). Poor emergence and frost were also important. Few respondents identified suitable cultivar as a limiting factor. Other concerns included false breaks, soil constraints and pre-emergent herbicide performance. These findings are consistent with a regional survey carried out in 2013 in WA (McNee *et al.* 2015).

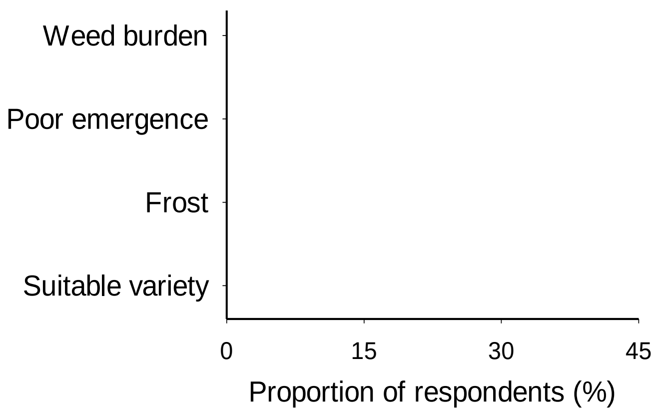

Figure 3. Results of Twitter poll (January 2019) of growers in South-eastern and South-western Australia ranking the most important management risks associated with early and dry sowing (n=535)

Paddock selection and pre-crop management

Paddock selection and pre-crop management are critical for the successful implementation of early sowing. Early sowing increases the reliance on in-season weed management as options for knockdown weed control are limited. Therefore choosing paddocks with low weed pressure is key to success. This can be achieved through various strategies including crop rotation, which minimises the weed seed bank (Seymour *et al.* 2012, Angus *et al.* 2015), and harvest weed seed control (HWSC) in the preceding crop. HWSC can include options such as chaff carts, windrow burning, crop topping and seed destruction (Walsh *et al.* 2013, see also Chapter 10) that minimise the return of weed seeds.

Topography is another important factor when choosing which paddocks to sow early or dry. Paddocks lower in the landscape are at additional risk of frost (Dixit and Chen 2011) and early sowing may exacerbate this further. Fletcher *et al.* (2015) demonstrated that, across a whole farm, dry sowing would give a small increase in the risk of frost particularly at the start of the sowing program. Therefore it is a beneficial strategy to sow winter canola and wheat cultivars first, followed by the paddocks with the least incidence of frost first, and higher risk paddocks last.

Soil type is also an important aspect of paddock choice for early sowing. In water repellent sandy soils, disturbance of dry soil can increase hydrophobicity (Roper *et al.* 2015), adversely affecting the germination and emergence of dry sown crops. Therefore, these soils are not recommended for dry sowing. Lighter sandy soils with lower soil water holding capacity require less rainfall to germinate dry sown crops, and are more suitable for large dry sowing programs (Fletcher *et al.* 2015).

Stored soil moisture is a trigger in the decision to sow early or not. Growers are more confident to dry sow if there is stored soil moisture (McNee *et al.* 2015) because once sufficient rainfall occurs to initiate germination, there is increased likelihood that stored soil water will sustain early crop growth. Long fallow (Oliver *et al.* 2010) and good summer weed control (Hunt and Kirkegaard 2011) can be used to maximise the stored soil moisture at sowing. A simulation study by Flohr *et al.* (2018a) showed that early sowing, deep sowing of long coleoptile wheat cultivars, or long fallow gave smaller increases in wheat yield when applied separately. However, when these three management approaches were combined, mean wheat yields increased by 42%.

In-season weed control

The importance of effective weed control as a management factor for early or dry sowing has been highlighted (Figure. 3, see also Chapter 10). When early sowing, the opportunity to use a double-knock weed-control strategy is foregone (Borger and Hashem 2007). The double knockdown weed control strategy is the sequential application of two different pre-planting herbicides with different modes of action (*e.g*. Glyphosate and paraquat). The double knock strategy is a valuable tool to delay the development of herbicide resistance in weed populations. In early or dry sowings, it is rarely possible to achieve a successful knockdown of grass weeds, as there is often limited soil moisture to stimulate germination of weeds. In populations that have evolved a greater degree of dormancy, weeds will not emerge until later in May. Early sowing systems limit the effectiveness of pre-emergent knockdown herbicides, whilst increasing the reliance on residual pre-emergent herbicides. However, the efficacy of many pre-emergent herbicides is dependent on an interaction with soil moisture, or a significant rain event following application; these conditions may influence efficacy of some residual chemicals at the time of weed germination. For example, Minkey (2017) found that pyroxasulfone applied on 15 April, had an efficacy of 50% after six weeks when applied on dry soil but only 10% when applied on wet soil.

An early sown crop has greater early vigour due to warmer soils, and a higher plant biomass that can shade and compete better with weeds than later sown crops. Preston *et al.* (2017) showed that a similar density of annual ryegrass plants established in wheat sown on 6 May compared with 2 June. However, the number of ryegrass spikes/m^2 was much lower in the early sown crop when compared in October (Figure 4). On average there was 1 spike/ryegrass plant when wheat was sown 6 May but 1.8 spikes/plant when wheat was sown 2 June. This increased weed competition from early sowing may help reduce the weed seed bank in future seasons especially if combined with new high vigour wheat genotypes (Zerner *et al.* 2016).

Fertiliser management

Early sown crops require different N fertiliser management than those sown in the conventional mid-late May window. In soils with low N, additional fertiliser N is required to maintain protein content and to attain potential yield, and also to manage the long term soil organic N which may decline under early sowing systems (Cossani *et al.* 2019). In high soil N scenarios, excessive N applied to early sown crops may lead to haying off and reduced yield. Identifying the economically appropriate fertiliser N rate is

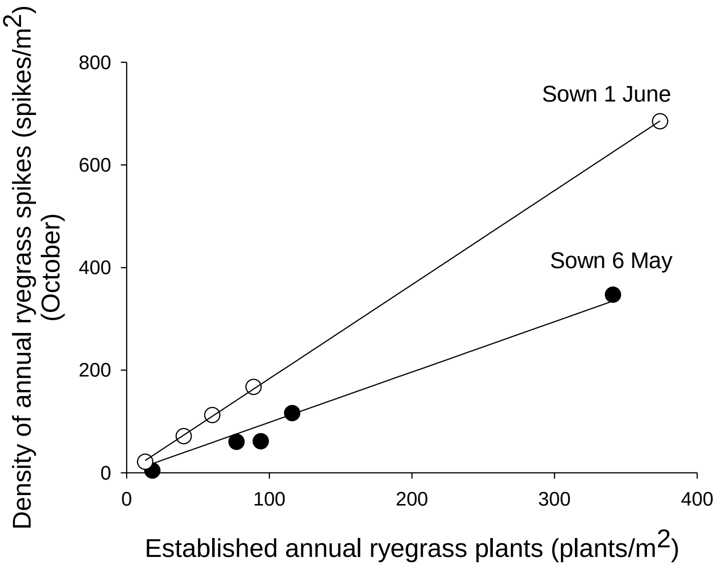

Figure 4. Effect of sowing time on the number of ryegrass spikes in a wheat crop at Roseworthy SA. Ryegrass densities are the result of pre-emergent herbicide use (redrawn from Preston *et al.* 2017)

more challenging in early sown crops, in particular in dry sown situations. When seasonal conditions and yield potential are unknown at the start of the growing season, growers often apply minimal N fertiliser inputs at sowing and rely on top dressing additional fertiliser N when seasonal conditions warrant further application.

Sowing rate and depth

Research has shown no significant yield benefit from altering seed density (50 vs 150 plants/m^2) in early-sown wheat crops (Porker *et al.* 2019). However, higher seed rates can increase the competitiveness of the wheat crop with weeds. Frequently growers sow deeper when sowing early to 'seek' stored soil moisture and ensure germination. However, higher soil temperatures in early sown crops may limit the depth from which wheat seed can emerge. Rebetzke *et al.* (2016, see also Chapter 17) found that in modern semi-dwarf cultivars the coleoptile length was 43% shorter under soil temperatures of 27 vs 15°C. However, there is genotypic variation in the coleoptile length amongst cultivars, and when sowing early and deep, cultivar choice needs to be adjusted accordingly. Alternative dwarfing genes with longer coleoptiles are currently under development to allow emergence from deeper planting (Rebetzke *et al.* 2007, Kirkegaard and Hunt 2010, Rebetzke *et al.* 2016).

When dry sowing canola there is a greater risk of a small rainfall event that triggers germination but may not be sufficient for continued growth. Due to the risk of poor establishment, sowing densities of early sown canola are often increased (Lilley *et al.* 2018), and seed is sown slightly deeper into wet soil to account for higher evaporation rates. However, deeper sowings lead to decreased germination and emergence (Brill *et al.* 2016) and this trade-off needs to be managed. In contrast, dry sown canola is often sown at a reduced depth to avoid the risk of partial germination (Lilley *et al.* 2018).

Logistical challenges in dry sown crops

There are logistical challenges associated with early sowing crop management. When large areas of a single cultivar have been dry sown, they will emerge at the same time and are at exactly the same growth stage requiring simultaneous in-season management, such as post-emergent herbicide, fungicide, and fertiliser N applications. Fletcher *et al.* (2015) showed that at the whole farm level, dry sowing leads to a more condensed and earlier flowering period compared to farms with no dry sowing. This can be advantageous in seasons ending with heat stress or terminal drought but only minimal increase in frost risk around flowering.

Risks associated with early/dry sowing

Abiotic stresses Early sowing without adjusting cultivar development type results in rapid developmental progression and early flowering, and thus an unacceptable level of frost risk and increased spikelet sterility in frosty seasons and frost-prone environments (Flohr *et al.* 2018b). Cropping programs that begin sowing earlier and sow an appropriate cultivar will have less area of crop at risk of heat stress during grain fill. Growers need to adjust the cultivar development type of both cereals (Flohr *et al.* 2017, 2018b) and canola (Lilley *et al.* 2015, 2019, Kirkegaard *e*t al. 2016) to target an optimum flowering window. There are marked differences in frost susceptibility between cereal species, and in many sowing programs barley and oats are sown early in preference to wheat due to reduced sensitivity to frost damage around flowering (DPIRD 2018).

Early sowing can help avoid terminal drought during grain fill by ensuring that grain fill is complete before soil water resources are depleted (Fletcher *et al.* 2015, Flohr *et al.* 2017). However, early sowing can increase the risk of the crop experiencing early soil moisture deficits that may lead to poor emergence, or even seedling death. Fletcher *et al.* (2015) demonstrated that this risk increased dramatically with dry sowing. However, this is rarely a problem, and it may even be beneficial as it will have the effect of seed priming for germination on later germinating rains (Passioura and Angus 2010). In contrast, Wallace (1960) showed that the viability of wheat seed declined when placed in soil that had sufficient moisture for imbibition but not enough to trigger full germination. This loss of viability depended on the soil moisture content and the length of time that the seed was exposed to these conditions (Figure 5). For example, at 15% soil moisture 70% of seed emerged during the initial 18 day period and the remaing 30% of seed was still able to germinate afterwards; but at 9% soil moisture no seed emerged during the initial 18 day period and only 35% of the remaining seed was viable. Growers can use medium term forecasts to dry sow ahead of a forecast rainfall event of sufficient size to ensure germination and emergence (Asseng *et al.* 2016). When sowing in March on heavy clay soils, at least 25 mm of rainfall and stored soil moisture was required for successful wheat establishment, but when sowing on lighter soils in April as little as 10 mm (in furrow irrigation) of water was required (Porker *et al.* 2019).

Early sown canola may be more susceptible to early soil moisture deficits due to its small seed. When sowing early into wet soil the risk of early season drought can be managed by ensuring that sufficient soil moisture for sustained growth is available from rainfall and stored soil moisture. Sharma *et al.* (2013) showed that about 35 mm of plant available soil water was sufficient to sustain plant numbers following initial germination for at least 5 weeks after early April sowing.

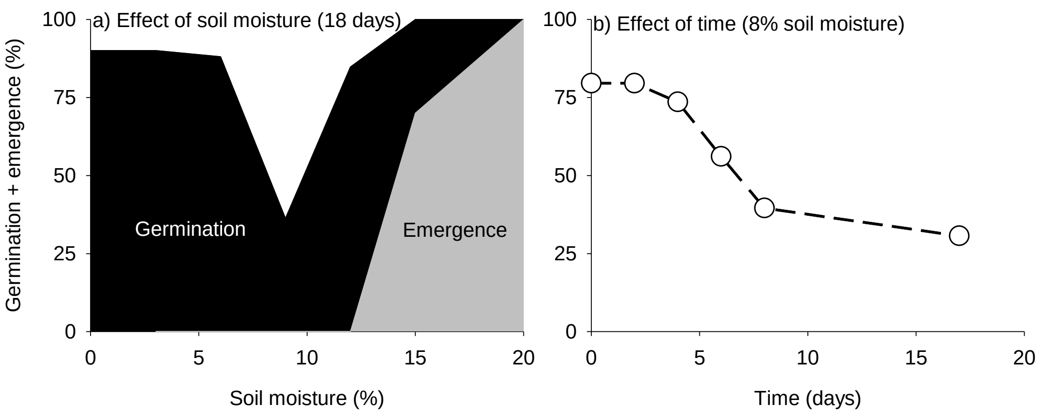

Figure 5. Effect of soil moisture on emergence of wheat seed after 18 days and subsequent germination (a); and number of days at 8% soil moisture on subsequent germination of wheat seed (b). Germination refers to seed that did not germinate and emerge during the 18 day treatment but that was still viable after this period (data from Wallace 1960)

Biotic stress Early established cereals are exposed to a range of new pathogens (Hunt 2017). These include barley yellow dwarf virus, wheat streak mosaic virus, stem and leaf rusts, and *Zymoseptoria tritici* (see Hunt 2017 for a more detailed discussion of the implications of these diseases in early sown cereals). Early

sowing of canola also influence the disease risk of canola. Both black leg (Leptosphaeria maculans) and sclerotinia (*Sclerotinia sclerotiorum)* can infect the upper canopy of canola and reduce yield. Sprague *et al.* (2017) demonstrated that early sown canola crops developed greater levels of upper canopy black leg infection compared with delayed sowing. For all crops, disease monitoring and management packages need to be adjusted in early sown crops.

Farming system implications of early sowing practices

Multiple cultivar storage and establishment opportunities

For a given location there is an optimum flowering window for both cereals and canola (Flohr *et al.* 2017, Lilley *et al.* 2019). For a given sowing date, the cultivar needs to be selected to ensure flowering occurs in this period (Figure 1, Hunt 2017, Flohr *et al.* 2018b, Hunt *et al.* 2019, Lilley *et al*, 2019). This means that in environments with variable and unpredictable sowing opportunities, a grower must store multiple cultivars on farm so that the right phenology type can be used for a given sowing opportunity. Yield benefits associated with early sowing of long season cultivars (particularly those in Mediterranean environments) can only occur provided that growers store cultivars with different development speeds on-farm, with no certainty of the area to be planted (or whether sowing opportunities occur at all in a given season) to each until the time when establishment opportunities are known. This varies from season-to season and between environments. For example, by 15 April a wet sowing opportunity has occurred in nearly 50% of seasons at Wagga Wagga NSW, 20% of seasons in Minnipa SA and Mildura Vic but only 13% of seasons in Merredin WA (Figure 6).

In seasons where the break has not occurred it is recommended that winter crop cultivars are not dry sown (Hunt 2017) as the risks of late emergence could mean that this phenology type is inappropriate. One approach is to sow mixtures of early and late cultivars to mitigate the risks of frost and heat (Fletcher *et al.* 2019). However, this approach requires further testing.

The need to store multiple cultivars is a possible barrier to adoption of this system, but given the probable yield increases at the whole farm level demonstrated in Hunt *et al.* (2019), growers will likely see value in adoption. A robust economic analysis of the benefits/risks of storing multiple cultivars on farm is urgently required. It is likely that the outcome of such an analysis will vary between sites depending on the frequency of early sowing opportunities (Figure 6). Innovation in seed sale swaps or multiple cultivar deal options from seed companies might be a way to operationalise and de-risk the need for multiple cultivars.

CA has been a facilitator of earlier sowing as growers no longer require as much or as frequent rainfall in order to sow their crops. However the benefits of early establishment in dryland farming are still ultimately dependent on irregular rainfall or stored soil moisture, and opportunities do not always exist to plant in early/mid-April (Penrose 1993). Field experiments and simulations studies have shown that early sowing systems can achieve yields similar or more than short-cycle cultivars sown later (Coventry *et al.* 1993, Penrose 1993). However the yield advantage expressed by early sown long-cycle cultivars in experiments conducted over decades has been variable (Frischke *et al.* 2015, Peake *et al.* 2018, Hunt *et al.* 2019). Hunt (2017) has speculated that the yield advantage of early sown long-cycle cultivars is only expressed in seasons where the soil profile fills with water during fallow periods, giving the crop greater access to water through longer root growth duration (Lilley and Kirkegaard 2016). Therefore in fine textured soils with high water holding capacity the incidence of establishment opportunities can potentially be increased where long fallowing and early sowing are used as complementary practices (Schillinger and Young 2014). The fallow helps to reduce weeds and disease which can be difficult to control in early sown crops; early sowing with slow developing cultivars allows the crop to have better use of water that is stored at depth in the soil during the fallow (Oliver *et al.* 2010). The breeding of cultivars with long coleoptiles that can be sown at depth into stored moisture could also enhance early sowing opportunities (Rebetzke *et al.* 1999). Though not experimentally evaluated, the fallow, deep sowing and long coleoptile cultivar synergy may offer a strategy to overcome limited early establishment opportunities of slow developing cultivars, and requires field validation under Australian conditions. The long fallow and winter wheat synergy is widely practised in low rainfall environments of United States Pacific Northwest, where yield increases of up to 1.6 t/ha have been observed relative to continuous spring wheat rotations (Schillinger and Young *2004).*

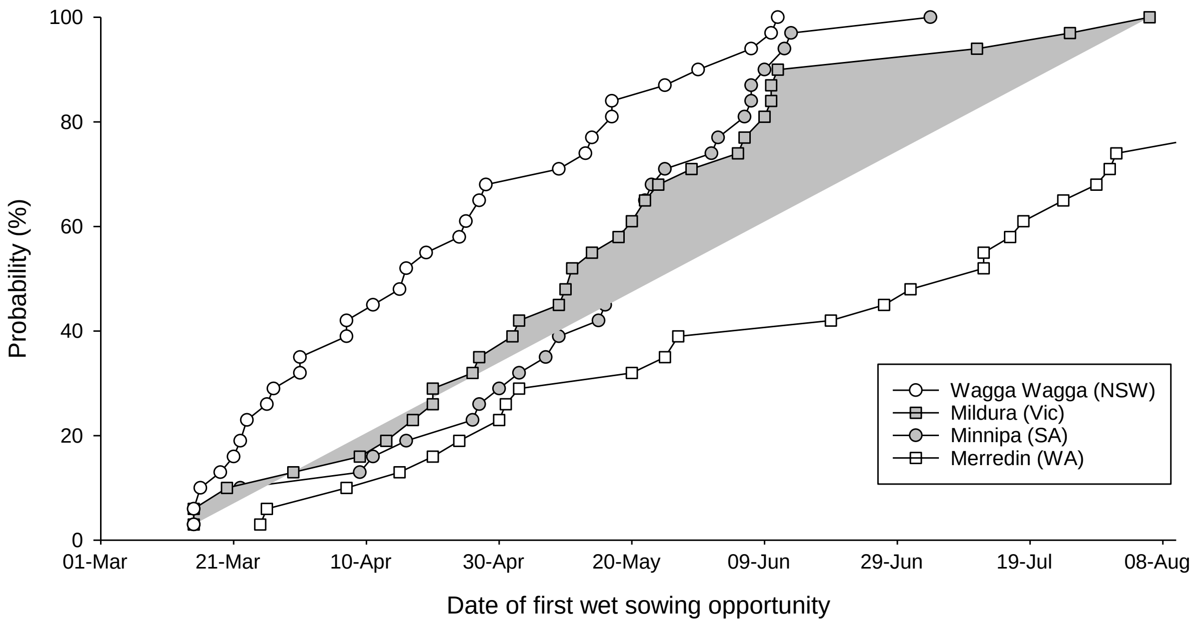

Figure 6. Probability distribution of first sowing opportunity for four representative sites across southern Australia from 1988-2018 using the methods of Unkovich (2010).

The place of early sowing in rotations

Under increasingly warm and variable climates, the efficient use of soil water carried over from the previous crop and of rainfall accumulated during fallow periods is an important element of the farming system (Lilley and Kirkegaard 2007, Hunt and Kirkegaard 2011). One consequence of a deeper root system and a higher yielding crop in one season is that the soil is left in drier state and potentially limits water availability for subsequent crops. A simulation study by Lilley and Kirkegaard (2016) showed that plant available water at sowing of a second crop in sequence was 2-21 mm less following early sowing in the first year compared with a normal sowing time. Historically, crop choice is driven by paddock history in relation to disease and weed break rotation, as well as grain price (Angus *et al.* 2015). As sowing becomes earlier, it is important that soil water availability at the start of the season is considered, and that the crop sequence is managed tactically to optimise the overall system utilisation of water (Lilley and Kirkegaard 2016). It may be preferable to alternate early and normal sowing times within a given paddock. Alternatively, alternating early sown wheat with a long fallow, brown manure, hay or legume crop that helps preserve soil water and N may form a robust crop rotation that also has the benefits of a disease and weed break.

Early sown dual-purpose crops in mixed-enterprises

Utilising early sowing opportunities with dual-purpose crops is a profitable system in mixed farming enterprises. A dual-purpose cereal or canola crop is one that is grazed when vegetative to fill an autumn-winter feed gap. The livestock are removed prior to stem elongation which enables the crop to recover and still produce grain (Virgona *et al.* 2006, Sprague *et al.* 2015). Early sowing combined with slow developing cultivars (Figure 2) results in a longer vegetative stage and greater biomass accumulation to fill the feed gap (McCormick *et al.* 2012, Bell *et al.* 2015). Early sown, dual-purpose crops have a longer vegetative stage and deeper root growth. They also provide early soil cover which can reduce erosion, evaporation and drainage of early rains (Bell *et al.* 2014).

Grower case studies

Early sowing in practice in southern NSW

John, Michelle, Brendan and Felicity Pattison

- *Location:* Marrar NSW
- *Area:* 1,500 ha
- *Mean annual rainfall:* 520 mm (GSR: 350 mm)
- *Soils:* Red loam, undulating
- *Enterprise mix:* Continuous cropping canola, wheat, barley, faba beans, lupins
- *Sowing capacity:* 80 ha/day

Sowing across the properties at Marrar commences irrespective of rain in early April, and is ideally completed by mid-May. In most years, crops are sown into moisture with a single disc seeder, which has been afforded by a combination of maintaining full stubble cover (cereals harvested with stripper front) and a rotational weed control strategy. Weed management is a key consideration, which includes an occasional tactical double break in their rotation, and strict summer weed control.

The sowing program commences with canola, progressing to winter wheats, lupins and fababeans, before the remainder of canola is sown prior to the previous benchmark start date of 25 April (Anzac Day). The program then shifts to sowing of longer-season wheat and barley cultivars before finishing with main-season wheat and barley cultivars. In total, sowing consists of 1-2 canola cultivars, 1 lupin and fababean and 2-3 wheat and barley cultivars with the aim to optimise yield and profitability across crops.

The aim is to sow cultivars close to their optimal sowing window, and the order of crops is adjusted as new cultivars are adopted. For example, there has been a clear shift in sowing dates, of up to three weeks in canola, where previously (1990s), they achieved highest yields when sown in early May. The Pattisons have been practising early sowing of cereals since the early 2000s when, as a mixed farming enterprise, they sowed dual-purpose wheats in late March to capture early grazing opportunities.

Early sowing limits pre-season weed control and increases pressure of pests such as mice, slugs and earwigs. However the tactical implementation of the double-break in rotation has reduced the reliance on knock-down herbicides. Pest control is implemented on a seasonal basis if required.

In the future, the Pattisons are interested in commencing sowing earlier, into March, provided that suitable winter cereal cultivars are available that do not need to be managed through grazing. There is also interest in the incorporation of companion cropping into their rotation, as this may offer alternatives to earlier sowing of single species as well as alternative crops, to increase diversity on-farm.

Early sowing in practice in southern WA

Nick and Tryph Gillett

- *Location:* Bencubbin WA
- *Area:* 11,000 ha (10,000 crop and 1,000 fallow)
- *Mean annual rainfall:* 305 mm
  GSR: 205 mm average; 165 mm past 10 years
- *Soils:*
  Sands, gravel sands, sandy loam, loam to strong clay loams
- *Enterprise mix:* Continuous cropping
  wheat (65%), barley (20%), canola (15%)
- *Sowing capacity:* 600 ha/day using 2 units

Seeding at the Gillett's property begins on 10-15 April with the aim of completing seeding by 15 May. Sowing begins irrespective of rainfall and they are happy to plant 100 % of the area dry if necessary. In 2018 they sowed 95% of their crop into dry soil. Sowing takes approximately one month to complete. Barley is normally sown first, followed by canola and then wheat. When possible, canola is sown onto land that was previously in fallow.

The Gilletts have moved to more dry seeding since the 2014 growing season. Severe heat stress in late September 2014 damaged late sown crops at their most vulnerable stage and this highlighted the benefits of sowing early. Previously, they started seeding on 25 April with a view to complete sowing on 10 June. The key drivers for the shift to early and dry sowing have been shorter seasons that highlighted the need to sow early. Also, smaller intensity rainfalls in autumn has meant the focus now aims to utilise small rainfall events rather than sowing into moist soil. Other factors that have made dry sowing possible include: the move to more stubble retention, resulting in a more friable seed bed; and bigger machinery with higher break out pressure tynes.

Nick finds that dry sown crops yield similarly to crops sown on the break of the season. Across his farm he gets more consistent yields using dry sowing as more crop area establishes at the optimal time. Dry sown crops can be less variable than crops sown following light rain. When heavy rain occurs soil crusting can reduce establishment on heavier soil types.

Weed control is the major issue with dry sowing. The weeds and crop emerge at the same time and there is no ability to use a double-knockdown herbicide strategy. Canola can be a useful tool in this respect due to the increased number of herbicide tolerant options. Frost can be an issue with early and dry sowing, although Nick has a geographical spread of crops which helps to mitigate this risk.

Nick does not know whether sowing will get earlier in the future, but he feels he has more to lose from sowing too late compared with sowing too early. Stored summer moisture is an important driver. With stored summer moisture Nick is more confident of sowing early whether into wet or dry soil. An emerging issue with dry sowing is the ability to judge the season and adjust inputs appropriately.

Looking to the future, Nick thinks that wheat cultivars with long coleoptiles that can be sown deep (>100 mm) into stored moisture might be beneficial to his cropping system.

Conclusions and opportunities for future research

In the last 30 years there has been a gradual evolution of sowing dates in southern Australia. Sowing dates have moved earlier by 1 to 1.5 days earlier per year, with a dramatic shift and wide spread adoption of dry sowing in the last 5 years (Fletcher *et al.* 2016, Flohr *et al.* 2018b). The drivers of this revolution have been increased cropping area as farmers seek to improve productivity per labour unit and reduced wet sowing opportunities. The trend towards earlier sowing has been facilitated by no-till and machinery improvements.

Current climate forecasts are limited and are only reliable up to 10 days out. Improved climate forecasting may improve grower confidence and reduce risk when making decisions regarding cultivar choice and utilising sowing opportunities prior to the 'breaking' rain (Lilley *et al.* 2019). As our understanding of crop development continues to improve, new cultivars will become available that are better suited to early sowing. Developments in marker assisted selection will aid with the identification of genotypes with the desired suite of traits. Ideally, growers will eventually have access to cultivars that can be sown over a wide range of sowing dates but still flower within the optimum window. Further success with early sowing systems and future yield gains requires continued interaction and collaboration between plant breeders, plant physiologists, agronomists and farmers.

Traits other than flowering time are likely to become increasingly important for early sowing systems. Target traits will include new long coleoptile wheats (Kirkegaard and Hunt 2010, Rebetzke *et al.* 2016, Flohr *et al.* 2018a) with slow development that can be sown early into stored moisture and flower during the OFP. This will also require modification of seeding equipment to enable deeper sowing. Weed control in early and dry sown systems is a key issue to overcome in order to facilitate further success. Therefore high vigour wheat cultivars (Zerner *et al.* 2016, Zhao *et al.* 2019) with weed competitive traits may become a key part of this system. Similarly, crop cultivars and species with new herbicide tolerances have an important role to play. It is unclear whether the competition advantages of early sowing will outweigh the disadvantages of lack of herbicide knockdown options. However, other options to manage the size of the weed seed bank such as crop rotation and harvest weed seed management, will likely become more important.

In the long term, as automation becomes widespread in agriculture the impetus to maximise productivity per labour unit may become relatively less important. For example, if robotic sowing units become available, growers will likely use more smaller units rather than one (or few) large sowing units, because a single operator can remotely control multiple units. In this automated future growers may be able to sow large areas of crop in a relatively short timeframe which would mean that dry sowing becomes less critical. Furthermore, as a new range of sensors are developed, technologies that sense soil moisture and adjust seeding depth automatically so that seed into soil moisture may help to avoid poor establishment. However, recent research has demonstrated that there are large possible yield benefits from early sowing (Flohr *et al.* 2018b, Hunt *et al.* 2019) suggesting that the adoption of early sowing will likely continue to increase.

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