

Drivers of trends in Australian canola productivity and future prospects

In Australia, canola was initially grown in more reliable rainfall areas (>400mm annual rainfall) due to its greater sensitivity to heat and drought than cereals, and the higher production costs increasing risk in more marginal environments (Colton and Potter, 1999). Improved varieties and agronomy, along with the overall farming systems benefits of weed and disease control in cereals, have expanded the area cultivated under canola, and it is now grown in all but the driest margins of the wheat belt.



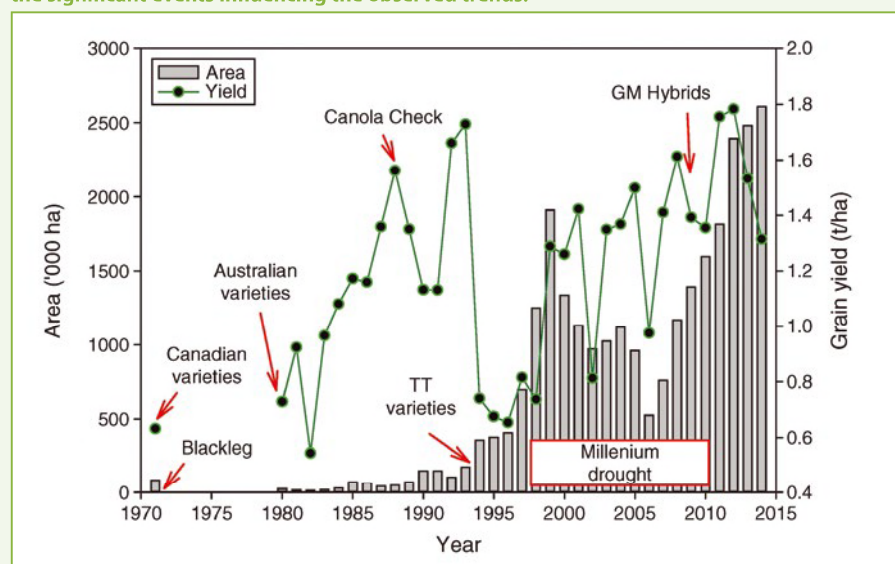
which favoured cereals such as wheat and barley over canola.

Yield levels maintained

As the area of canola declined and the crop retreated to the more reliable rainfall areas, overall yield levels were

maintained, except for the notable drought-stricken years of 2002 and 2006. Although some interannual variability in area and yield is likely to continue in response to seasonal conditions and relative prices, the current area is at an all-time high (Figure 1).

Figure 1: Area and average national grain yield for canola in Australia, highlighting some of the significant events influencing the observed trends.



The linear trends (not shown) in grain yield fitted for the years 1980 to 1993 and 1998 to 2014, were 67kg/ha/year (3.8% p.a. of 1993 yields) and 34kg/ha/year (2% p.a. of 2014 yields), respectively. These periods represented times of relatively stable production areas of <0.3Mha before release of TT varieties, and 1 to 2Mha after the release of TT varieties. Data compiled from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) estimates (2014) and Australian Oilseeds Federation (AOF) estimates (2015).

A previous review of Australian canola productivity in 1999 ironically marked the beginning of a rapid decline in canola-planted area to approximately 0.5Mha in 2006, which resulted from a combination of poor seasonal conditions and changing terms of trade (Figure 1). During its swift expansion in the late 1990s, canola extended beyond the traditional, more reliable rainfall areas (annual rainfall >450mm) and into lower rainfall areas (<32 mm) especially in Western Australia, and in some cases onto less suitable soils.

The period from 1998 to 2010, now known in that country as the millennium drought (Verdon-Kidd et al., 2014) was characterised by dry autumns, late planting rains and limited soil water storage, together with hot, dry springs

As a result of the significant fluctuations in the areas sown to canola in Australia it is hard to establish meaningful overall yield trends, but the impressive early improvements were clear, rising from around 0,6t/ha in the 1970s to 1,8 t/ha in 1993 (*Figure 1*). This was largely due to the development of adapted, blackleg-resistant varieties (Salisbury and Wratten, 1999; Buzza, 2007; Cowling, 2007), along with highly successful agronomy packages such as CanolaCheck (Colton and Potter, 1999). The yield progress during this early period on the small (<0,3Mha) but relatively stable higher rainfall areas was a remarkable 67kg/ha/year or 3,8% p.a. (based on 1993 yields).

The introduction of triazine-tolerant (TT) varieties in 1993 led to an expansion of canola into more marginal areas of Western Australia, which combined with their inherently lower yield potential (Robertson et al., 2002b), and a devastating drought in 1994 saw average national yields collapse for several years as the area grown increased (*Figure 1*).

During the subsequent millennium drought period from 1998 to 2010 (Verdon-Kidd et al., 2014), the area stabilised at around 1Mha, and in the period 1998 to 2014 average yields steadily returned to the levels achieved in 1999. The linear yield trend during the 16-year period 1998 to 2014 was 34kg/ha/year or 2% p.a. based on 2014 yields, but in this case coincided with an increase in the area grown (*Figure 1*).

Crop comparisons

This basic estimate of recent national farm yield progress compares well with those established for the period 1991 to 2010 by Fischer et al. (2014) for China (37kg/ha/year, 2%) and Canada (33kg/ha/year, 1,7%), exceeding that of India (15kg/ha/year, 1,4%) and France (21kg/ha/year, 0,6%) but indicating a figure lower than that achieved in Germany (68 kg/ha/year, 1,7%).

A more recent estimate for yield gain in the Canadian Prairies for the period 2000 to 2013 is 54kg/ha/year or 2,6% per annum relative to 2013 yields, and factors driving this increase are discussed by

Morrison et al. (2016a). National trends of farm yield are of interest, but in order to drive productivity gains it is vital to compare current performance against a defensible yield potential to assess the exploitable yield gap between potential yield and that achieved in farmer's fields (Kirkegaard et al., 2006; Fischer et al., 2014).

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Yield potential can be estimated by simple crop comparisons (e.g. canola yield = 50–60% of wheat yield) (Holland et al., 1999), expected seasonal water-use efficiency (WUE) [e.g. 15kg/ha/mm of seasonal evapotranspiration (ET)] (Robertson and Kirkegaard, 2005), or crop simulation models sensitive to crop, soil, climate and management factors (Kirkegaard et al., 2006; Lilley et al., 2015).

The latter approach has recently been used to estimate potential canola yields and yield gaps on statistical local area (SLA) scale for the entire nation for the period 1998 to 2015, and has been made available in a web-based format. The analysis suggests that the overall average farm yields across 162 SLAs in the period 1998 to 2012 (range 0,9 to 1,4t/ha) were 42 to 68% of the water-limited potential yield (range 1,3 to 3,2t/ha) assessed using the simulation analysis.

Scope to increase productivity

A further estimate of yield potential can also be assessed from field experiments evaluating the latest varieties under optimum agronomy, such as those that have been conducted as part of the National Variety Testing (NVT) series across Australia for canola since 2005.

A summary of the site mean yields

achieved across a range of NVT sites in the period 2005 to 2014 confirms that for elite varieties under experimental conditions, average yields of 2,5 to 3t/ha and 1 to 2t/ha can be achieved in high- and low-rainfall sites, respectively.

Together these measured and modelled estimates of current yield gaps in canola suggest there exists significant scope to increase canola productivity on the country's farms with ongoing research, development and adoption of new technologies.

Key strategies

The early strategies and success of Australian canola breeders in developing adapted, disease-resistant varieties producing high oil yields of good quality have been previously reviewed (Salisbury and Wratten, 1999; Buzza, 2007; Cowling, 2007). Potter et al. (2016) report a study of historic non-herbicide-tolerant (NHT) canola varieties, suggesting genetic improvements may have contributed around 21,8kg/ha/year (or 1,25% p.a.) to overall yield improvement in the period 1978 to 2012.

However, the remarkable success of major global competitors such as Canada in achieving continuing improvements in yield and quality (Morrison et al., 2016a), highlights the need for ongoing innovation in the Australian industry to remain competitive.

The initial targets for Australian breeders – blackleg resistance, high yield and quality – remain the key targets for breeders today. Salisbury et al. (2016) chart the ongoing innovation in that nation's canola breeding in these chief areas and highlight some of the changes during the last 15 years. These include the switch from public to private breeding and the associated diversification in the genetic background of Australian canola, a concern previously discussed by Cowling (2007).

This has increased the development and release of hybrid varieties, new herbicide-tolerant types including genetically modified (GM) glyphosate-resistant crops, also known as 'Roundup Ready' (RR) varieties in 2008, new

speciality oil types, as well as new sources of blackleg resistance. In 2013, open-pollinated, TT varieties still comprised 81 and 70% of canola grown in Western and South-Eastern Australia, respectively, but the focus of breeding companies has switched to hybrid varieties with a declining number of new open-pollinated releases in recent years (Zhang et al., 2016).

New technologies

The increasing use of new technologies such as doubled haploidy, molecular markers and genomic selection and a range of other 'omics' technologies are likely to accelerate the identification of promising alleles for a range of traits and their breeding into elite varieties (Raman et al., 2016).

In the area of blackleg resistance, Van de Wouw et al. (2016) outline the significance of the increased recent understanding of the genetics controlling the interaction between *L. maculans* isolates and *Brassica* varieties, which has underpinned new breeding and management strategies to manage this devastating disease.

As canola production intensifies, managing the durability of polygenetic resistance presents the major challenge for the future and will require integrated approaches of new genetic resistance, new fungicide chemistry and improved cultural practices.

Nelson et al. (2016) describe the potential application of genomics to improve the phenological adaptation of canola which is a key driver for increased productivity in diverse and changing environments. Understanding the genetics controlling responses to vernalisation and photoperiod in wheat and using them as markers in breeding programmes and predictive models (Zheng et al., 2013), can unlock tremendous potential to tailor new varieties to specific environments with significant increases in yield potential. Such research is currently envisioned for canola (Nelson et al., 2016).

In addition to improved phenological adaptation, breeders and geneticists are also seeking further specific traits to improve the adaptation of canola to



drought (Norton 2007). Numerous traits such as carbon isotope discrimination, water-soluble carbohydrate remobilisation, osmotic adjustment, deeper roots, early vigour and canopy architecture have been investigated in cereals with ideotypes proposed (e.g. Reynolds and Tuberosa, 2008), but these are yet to be confirmed as beneficial in canola.

Breeding targets

As a result, there is currently little trait-based breeding in Australian canola, although the National Brassica Germplasm Improvement Programme (NBGIP) has initiated investigations of drought tolerance as a breeding target.

The ongoing empirical selection for early vigour, reduced height, flowering date and the move to hybrid varieties is likely to see ongoing improvements in yield under drier environments (Salisbury et al., 2016). The release in 2015 of a variety with a pod-shatter resistance trait (IH51-RR) may increase harvested yield under direct heading and in situations where harvest is delayed by rainfall or contractor availability.

In terms of canola quality, Potter et al. (2016) report that simultaneous improvements in both oil content (0.09% p.a.) and protein (0.05% p.a.) had been achieved over the period 1978 to 2012, while glucosinolate content was decreased from 7–16 µmol/g of meal by the mid-1990s. Innovative selection protocols indicate continuing improvements in the most recent releases

(Salisbury et al., 2016).

Further innovations in the Australian industry have consisted of high-stability oils, high in oleic acid and low in linolenic acid (Maher et al., 2007) and other speciality types, including recent development of canola varieties high in 'fish oil' omega-3 fatty acids, heralding a new era of speciality 'designer' oils (Lu et al., 2011).

At the time of writing, 44 varieties of canola were available to growers in New South Wales (NSW), including open-pollinated and hybrid varieties, five herbicide-resistant categories, conventional, triazine, imidazolinone (Clearfield), glyphosate (Roundup) and Roundup + triazine (RT), four different maturity classes, speciality oil types, winter grazing types and a pod-shatter resistance type (Matthews et al., 2015). This range of choice explains the wide adaptation and farming systems that canola has achieved across such a vast area of the country's cropping zone.

Farming systems evolution

The farming systems benefits of canola as a break crop for weed and disease control in cereal cropping systems have always been a major driver for adoption (Norton et al., 1999; Kirkegaard et al., 2008; Angus et al., 2015).

Originally canola was grown as the first crop after grass-clover pastures to control weeds and diseases before a sequence of cereals, and to capitalise on the high availability in relatively short (2–4 years) crop phases (Norton et al., 1999). However, as cropping intensity in Australia has increased at the expense of pasture area, canola is now grown more intensively in longer or even continuous crop sequences, often further down the rotation (Norton 2016).

This change in the farming system, together with recent changes in climate, adoption of modern no-till seeding technologies and the availability of new herbicide-tolerant and vigorous hybrid varieties (Zhang et al., 2016), has stimulated a re-examination of several aspects of canola agronomy in recent years.

Increasing the intensity of canola

production and its frequency in the crop sequence generates a significantly increased risk of blackleg, which requires more attention to in-paddock stubble management, separation from nearby infected residues and the rotation of canola varieties according to major resistance genes (Van de Wouw et al., 2016).

In Germany, where canola area doubled to 1,5Mt from 1990 to 2013 at a time when total agricultural area declined, Hegewald et al. (2016) have demonstrated associated reduction in seed (12%) and oil yield (14,6%) associated with increasing the intensity of canola production, despite full fungicide programmes applied to the crops.

Increased blackleg incidence

Although the cause of the yield decline in this study was not identified, similar studies in Canada using spring canola have demonstrated increased blackleg incidence and root maggot (*Delia* spp.) damage, both being implicated in yield decline as canola frequency increased (Harker et al., 2015).

Sowing times, seeding technologies and plant density targets have also been re-evaluated in different regions in the face of climate, equipment and varietal changes in recent years (Brill et al., 2015). The traditional optimal sowing window of late April to early May in Eastern Australia has been re-evaluated by Kirkegaard et al. (2016), who reviewed nine field studies (2002 to 2012) and conducted simulation analysis to investigate the benefits of earlier April sowing.

The study demonstrated declines in seed yield (-6,0 to -6,5%), oil content (-0,5 to -1,5%) and WUE (-3,8 to -5,5%) for each week-long delay in sowing after early April, suggesting opportunities to develop new earlier sowing strategies with appropriate varieties to increase productivity.

Brill et al. (2016) has shown that the risks of poor establishment in early sown crops, which are often sown deeply (>30mm) into stored moisture, can be reduced by increasing seed size, either by using hybrid varieties with inherently

larger seed or screening open-pollinated seed to >2mm diameter.

Optimum plant density

The higher cost and increased vigour of hybrid seed (Zhang et al., 2016) has also stimulated a re-evaluation of the optimum plant density required in different environments. Recommended plant density for canola was originally 50 to 70 plants/m² (Walton et al., 1999), but has gradually been revised down to between 30 and 50 plants/m² (GRDC 2009), although the recommended rates vary with region and row configuration.

Originally canola was grown as the first crop after grass-clover pastures to control weeds.

In a study comprising 24 experiments in the low- and medium-rainfall areas of Western Australia, French et al. (2016) found a median economic optimum density of 32 plants/m², but this differed for hybrid RR varieties (25 plants/m²), hybrid TT varieties (30 plants/m²) and farmer-saved, open-pollinated TT varieties (75 plants/m²).

Clearly there appears to be scope to adjust seeding rates according to variety choice and yield potential in different environments, but plant densities <20 plants/m² were less able to suppress annual ryegrass weeds. Therefore, maintaining adequate plant population is a key consideration in contemporary farming systems.

The changing position of canola in the rotation has increased the reliance of this oilseed on nitrogen (N) fertiliser, which is often the most limiting nutrient in canola production and the highest single input cost for growers. Norton (2016) provides a comprehensive review of the evolution of current N management in Australian canola.

Overall, there are few reported interactions between variety and N rates, and most growers use a budgeted N

rate requirement of 80kg N/t expected seed yield less indigenous N supply. Split applications provide options to delay decisions until there is more certainty regarding seasonal conditions with minimal loss in agronomic efficiency.

Reduce input costs

The recognised reduction in seed oil content associated with N application (-0,03 to -0,13%/kg N) is generally offset economically by the yield response, but this was not the case in a recent study conducted in the low-rainfall areas of Western Australia (Seymour et al., 2016).

In that study, while seed yield reached 90% of maximum at 46kg N/ha, gross margin was maximised at 17kg/ha N due to the relatively small yield increase compared to oil content decrease in response to N in that environment, and the uncapped premium price paid for oil content >42%.

Given that the relative yield and profit of hybrid compared to open-pollinated varieties declines in these lower rainfall environments, there will be ongoing efforts to reduce input costs in hybrid systems, and the continued availability of open-pollinated varieties will be advocated for such areas (Zhang et al., 2016).

As for the recent innovations that have led to increased productivity in Canadian Prairie canola production systems (Morrison et al., 2016a), there clearly exists an ongoing need to re-examine best management practices in the canola production systems in different regions of Australia, as farming systems evolve with new varieties and practices.

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