Crop modelling for the Australian canola industry: a review

MJ Robertson and JA Kirkegaard

CSIRO Sustainable Ecosystems, 306 Carmody Rd, St Lucia, Qld
CSIRO Plant Industry, GPO Box 1600 Canberra, ACT 2601

Abstract

We describe some recent uses of the Agricultural Production Systems Simulator (APSIM) in the Australian canola industry:

- penalties associated with delayed sowing in Western Australia,
- determining limits to potential yield in southern NSW,
- managing frost risk in the northern region,
- working with growers to improve confidence.

An assessment of current model accuracy is given as well as areas for future improvement.

Introduction

Crop-soil modelling has become an integral tool of trade to modern agronomic research. Well-tested and parameterised models can aid the analysis, interpretation and extrapolation of research findings through:

- Benchmarking crop performance. Models can be used to answer the question ‘Are crops yielding to their potential based on the climatic conditions experienced, the agronomic inputs (for example, fertiliser, density) and cultivar?’
- Disentangling the confounding influence of seasonal conditions on crop response to variety and agronomic management. This helps both researchers and farmers extend their understanding beyond the specifics of a particular paddock and season, separate contributions that various factors make to yield variation, and devise management strategies that will succeed in the long run.
- Exploring management options to overcome yield limitations. A well-configured model with enough flexibility and local parameterisation can be used to explore various scenarios for crop management that might be outside the scope or resources of an experimental program. It is also a useful approach to use in a ‘What If?’ mode with growers and consultants to evaluate alternative management strategies.

In this paper we describe some examples of where modelling, specifically the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2002; Robertson et al. 2000, Robertson et al. 2002a), has been used to add value to research and development for the Australian canola industry. Apart from the examples that are described below modelling has also been used to analyse the effect of wild radish infestation on canola yields in southern NSW (Robertson et al. 2001), the contribution of early crop vigour to improved water use efficiency in the Wimmera (Lythgoe 2002), and seasonal variability in yield and oil content in the northern region (Robertson and Holland 2003).

The APSIM-Canola model simulates crop development (phenology), growth, yield, water uptake and nitrogen uptake in response to temperature, photoperiod, radiation, soil water and nitrogen supply. The model uses a daily time-step and is driven by daily weather inputs. It calculates the potential yield, that is, the yield not limited by weeds, pests and diseases, but limited only by temperature, solar radiation, water and nitrogen supply. The scientific content of the model is a product of recent Australian research on canola crop physiology (e.g. Robertson et al. 2002b,c) building upon our current understanding of how the canola crop grows (Mendham and Salisbury 1995) and recent European efforts at rapeseed modelling (Gabrielle et al. 1998).

How good are we at predicting yield and oil content?

An important attribute of any model is its ability to simulate variables of interest with reasonable accuracy over the domain of interest. Over the last four years the canola module of APSIM has been tested comprehensively against crop and soil data from a broad range of conditions, in all mainland canola-growing states in Australia and in both experimental and commercial crops (Table 39).
Table 39: Summary of tests of APSIM-Canola against observed yield data.

<table>
<thead>
<tr>
<th>Location</th>
<th>N</th>
<th>Treatments</th>
<th>Yield (t/ha)</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Obs. range</td>
<td>RMSD^1</td>
</tr>
<tr>
<td>NSW, QLD, Vic</td>
<td>37</td>
<td>Sowing date, N, cultivar, irrigation</td>
<td>0.38–4.80</td>
<td>0.45 Robertson et al. 1999</td>
</tr>
<tr>
<td>WA</td>
<td>28</td>
<td>Sowing date, cultivar, location</td>
<td>0.10–3.2</td>
<td>0.35 Farre et al. 2002</td>
</tr>
<tr>
<td>Qld, northern</td>
<td>28</td>
<td>Sowing date, location</td>
<td>0.39–3.0</td>
<td>0.33 Robertson and Holland 2003</td>
</tr>
<tr>
<td>NSW</td>
<td></td>
<td>Cultivar, density</td>
<td>1.2–1.75</td>
<td>0.38 Lythgoe 2002</td>
</tr>
</tbody>
</table>

^1 RMSD = root mean squared deviation.

Yield ranged from crop failure to nearly 5 t/ha. Tests are surprisingly consistent in that the average error between the model and observed yields (represented by the root mean squared deviation) is about 0.4 t/ha. This is consistent with the accuracy of other crop models being currently used in Australia.

Phenology is an important cultivar attribute and determinant of crop performance. Parameters describing the environmental control of days to flowering were developed for a broad range of Australian canola and mustard germplasm (Robertson et al. 2002b; Farre et al. 2002), using a combination of phenology measurements in the field and controlled environments. The model incorporates responses to vernalisation, daylength and temperature, all of which were shown to be instrumental in determining time to flowering. The model accounts for the range of genotype and environment effects likely to be encountered in the Australian canola industry. We have confirmed that phenological parameters such as cardinal temperatures, and critical and base photoperiods are consistent with previous studies. We found that canola and Indian mustard could be analysed using the same model framework. All of the genotypes studied responded to photoperiod and vernalisation. Later-flowering genotypes had stronger responses to both vernalisation and photoperiod than early-flowering genotypes. There was no clear separation between the responses seen in Indian mustard from those in canola, indeed Indian mustard genotypes behaved as if they were early-flowering canola genotypes. These studies have shown that the average error in prediction of days to flowering is quite consistent at about four days.

In contrast to the simulation of growth, yield and phenology our current capabilities to predict environmental effects on oil content are based on more empirical methods. In addition to cultivar effects, we know oil content is affected by temperature, water deficit and nitrogen supply during grain filling. Various workers have used statistical techniques to relate oil content to temperature (e.g. Walton 1999), and temperature and rainfall (e.g. Si et al. 1999) conditions during grain filling. However, to date there has been no development of a more mechanistic method to predict oil content of a given cultivar across a wide range of environments and then use this to assess variability in oil content along with variability in yield. Recently we developed a semi-mechanistic method for simulating oil content using a dataset (n=51) comprised solely of cv. Monty, where oil content varied from 31.5 to 48.0%. The model, accounting for temperature and water deficit effects during grain-filling, had a RMSD of 2.1% (Figure 14).

![Figure 14](image-url)  
**Figure 14:** Observed versus fitted oil content for a new model accounting for temperature and water deficit effects. Shown are the 1:1 line of perfect agreement and the line of the linear regression between observed and fitted oil content.

Apart from phenological differences, the other cultivar characteristic that we are reasonably confident in simulating is triazine tolerance. Based on the work of Robertson et al. (2002c), Lythgoe (2002) was able to simulate the growth and yield differences between Dunkeld (a conventional cultivar) and Pinnacle (a triazine-tolerant cultivar) in the Wimmera (Figure 15) and then go on to explore...
the consequences of differences in early growth for water use and water use efficiency, growth and yield.

Further advances in our ability to simulate canola productivity will come as we deepen our knowledge of the physiology of the plant. Areas that we remain largely ignorant of are:

- root development and activity
- oil accumulation
- the effects of nutrients other than nitrogen (e.g. P)
- responses to row spacing.

In addition the physiological basis for differences between *B. napus* and *B. juncea* need further elaboration following the work of Wright *et al.* (1995).

![Figure 15: Observed and simulated grain and shoot biomass for Dunkeld (solid) and Pinnacle (dotted) in 1999 at Longerenong, Victoria.](image)

Penalties associated with delayed sowing

Canola is a relatively new crop in the Mediterranean environment of Western Australia and growers need information on crop management to maximize profitability. In this environment sowing date varies from year to year in accordance with the onset of rainfall. As sowing date is an important determinant of yield, yield varies from year to year. In environments with large season-to-season variability in rainfall, it is difficult to formulate strategies for consistent production of profitable canola crops. In designing a crop production strategy that accounts for the effects of location, soil type and cultivar, Farre *et al.* (2002) examined through simulation the yield penalties associated with delayed sowing, and the latest possible sowing date to achieve a target yield.

Farre (2002) tested the APSIM-Canola model against data from Western Australian using the experimental data of Walton (1999) (Figure 16).

![Figure 16: Simulated (●) and observed (○) grain yield with sowing date at Mt Barker and Wongan Hills, WA with cvs. Karoo and Oscar in 1998. The observed yield for Karoo at Mt Barker in the first sowing date was not available due to blackleg disease.](image)

These experiments included different locations, cultivars and sowing dates. The yield reduction with delayed sowing date in the high, medium and low rainfall regions (3.2, 6.1 and 8.6% per week, respectively) was accurately simulated by the model (1.1, 6.7 and 10.3% per week, respectively). The validated model is now being used along with historical climate data to derive sowing date recommendations for different rainfall regions in Western Australia. These analyses are showing that yield penalties for low rainfall regions are much higher than in wetter locations, emphasising the importance of timely sowing with the break of the season in drier locations.

What is the potential yield of canola in southern NSW?

In southern NSW concern has been growing that canola is not reaching its water-limited potential and in some areas yields are declining. In the high rainfall zone (550–600 mm) potential average canola yields are considered to be 3.5–4.0 t/ha while farmer yields are declining from an average of 2.0 t/ha in recent years. The Best Bet Canola Management Project, funded by NSW GrainGrowers and managed by a committee of growers, consultants and scientists was established in 2001 to identify factors causing poor canola performance. In 2001 and 2002, field
experiments focussed on the impacts of disease (Blackleg and Sclerotinia) and included seed and fertiliser fungicide treatments, foliar sprays for Sclerotinia, three sowing dates and two varieties (Rainbow and Hyola 60). Simulation modelling was used to estimate crop performance in relation to its potential, and to provide context to the field results in relation to expected seasonal variation in the region.

**Importance of accounting for seasonal variation**

Canola production in Australia is subject to immense seasonal variability associated with climate. Simulation models when coupled to historical climate data are powerful tools in quantifying the degree of this variability. While southern NSW is regarded as a fairly reliable high rainfall environment for canola production, long-term simulations reveal variation in potential yield from less than 1 t/ha to ca. 5 t/ha in the best of seasons (Figure 17). There is no obvious trend in yield ‘decline’ in this data suggesting that this perception is not climate related. In fact, the last 10 years or so in southern NSW has experienced mean growing season rainfall above the long-term average (Table 40). Research results during this growth phase of the canola industry will be biased towards this ‘run’ of above-average seasons.

![Figure 17: Variability in potential yield of canola at Harden.](image)

Simulations assumed a 15th May sowing each year with cv. Rainbow and high nitrogen supply. Soil type was a sandy clay loam.

**Table 40: Variability in growing season (April to October) rainfall (mm) for four canola-growing locations in southern NSW using the 1957–2000 climate record.**

<table>
<thead>
<tr>
<th></th>
<th>Cootamundra</th>
<th>Galong</th>
<th>Harden</th>
<th>Wallendbeen</th>
</tr>
</thead>
<tbody>
<tr>
<td>10th percentile</td>
<td>266</td>
<td>293</td>
<td>247</td>
<td>316</td>
</tr>
<tr>
<td>90th percentile</td>
<td>517</td>
<td>584</td>
<td>501</td>
<td>591</td>
</tr>
<tr>
<td>Average</td>
<td>413</td>
<td>430</td>
<td>374</td>
<td>453</td>
</tr>
<tr>
<td>Average 1990–2000</td>
<td>437</td>
<td>485</td>
<td>412</td>
<td>495</td>
</tr>
</tbody>
</table>
Benchmarking yields

An important question for this project was ‘Are crops, when controlled for disease yielding to their potential, based on management inputs, soil type and seasonal conditions?’ In order to calculate potential yield with APSIM, data was collected at the sites:

- daily climate
- soil water holding capacity
- available soil water and mineral nitrogen at sowing
- density
- cultivar
- sowing date
- fertiliser-nitrogen applied

Estimates of potential yield agreed well with hand-harvested measures of grain yield (Table 41).

The potential yield varied over the two seasons, depending upon rainfall, and soil water and nitrogen available for crop growth. In 2001 at Wallendbeen yields were in the top 10% of those expected historically, while at Galong yield was close to the long-term average. In 2002, Wallendbeen yield was in the bottom 10% of the long-term yield distribution, while at Galong yield was close to the long-term average. Disease-free crops achieved very high yields equal to the potential estimated by the model, suggesting that there were no other known constraints on yield other than those being captured by the model. These yields represent the upper limit of what is attainable in commercial crops and establish an important benchmark for the project.

One of the strongest determinants of potential yield open to manipulation by the grower is sowing date. As sowing is delayed the crop duration is shortened and a later grain-filling period is more likely to encounter high temperature and water deficit, which are both prejudicial to high yield. It is unclear to what extent early sowing is necessary to achieving high yields, and hence sowing date was a factor included in the experiments. Simulations studies using long-term climate data were used to put into context the results from the two seasons. The simulations confirmed the experimental findings in both seasons (Figure 18), that yield falls by about 25 kg/ha for each day’s delay in sowing. Surprisingly, the yield penalty is similar in good and poor seasons.

![Figure 18: Observed response to sowing date in 2001 and 2002 at Galong and long term simulated response on average, and in decile 1 and decile 9 seasons.](image)

Table 41: Measured and simulated potential yield in five crops (cv. Rainbow) with good disease control over two seasons in southern NSW.

<table>
<thead>
<tr>
<th>Season</th>
<th>Location</th>
<th>Yield (t/ha)</th>
<th>Long term yield expectation (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measured</td>
<td>Potential</td>
</tr>
<tr>
<td>2001</td>
<td>Wallendbeen</td>
<td>5.2</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Galong</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Harden</td>
<td>3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>2002</td>
<td>Wallendbeen</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Galong</td>
<td>3.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Long-term yield distribution is also given.
Crops were all sown in early-mid-May.
Understanding timing of nitrogen requirements

In high rainfall environments of southern NSW, the timely supply of nitrogen to meet crop demand can be crucial to achieving potential yields. At Galong in 2001, the three sowings differed in the level of available soil-nitrogen at sowing:

- Sowing 1 = 436 kg N/ha
- Sowing 2 = 345 kg N/ha
- Sowing 3 = 230 kg N/ha

At the end of the season, simulations revealed that Sowings 1 and 2 were probably not nitrogen limited throughout the season, while Sowing 3 may have experienced some nitrogen stress around flowering that would have contributed to this sowing’s lower yield potential. This experience highlighted the considerable nitrogen requirement of high yielding crops, and suggested that the crop in Sowing 3 may have benefited for a side dressing of nitrogen in late vegetative growth. The use of simulations to be run in ‘real time’ mode throughout the season was considered an appealing tactic to alert the grower to an imminent nitrogen deficiency. In the 2002 season at Wallendbeen we monitored crop and soil-nitrogen status by using the available soil-nitrogen at sowing (77 kg N/ha) and the dates and amounts of fertiliser nitrogen (6th April 60 kg N/ha urea; at sowing 10 kg N/ha; 17th July 46 kg N/ha urea) as input to simulations that were run through the season on a regular basis with updated rainfall data. By late August in Sowing 1 the simulations indicated that there was probably less than 20 kg N/ha left in the profile and so a side dressing of 46 kg N/ha was applied on the 3rd September. Consequently, the crop probably only experienced a brief period of nitrogen stress in late vegetative growth. In contrast, in Sowing 3 which had a lower yield potential and less demand for nitrogen, soil-nitrogen remained above 20 kg N/ha until late September. In this case the side dressing was probably not needed, as minimum nitrogen stress was experienced by the crop.

This example highlights the value of simulation, when coupled with crop and soil monitoring, in identifying limitations to productivity. It has raised awareness with growers and consultants of nitrogen management in high yielding crops that are being grown in the high rainfall zone.

Developing recommendations for managing frost risk in the northern region

Until recently it was assumed that inappropriate phenological adaptation of canola had lead to its poor performance in northern environments. For example, experiences with canola in the northern region in the late 1980s and early 1990s suggested that, with the then current cultivars and early-season sowing, the risk of yield damaging frosts was high. In a survey of northern canola growers, frost risk was ranked the second highest risk factor out of a list that also contained harvesting losses, high temperatures during grain-filling and planting opportunities. Traditional practice in the northern grain belt is to sow winter grain crops in early-May to late-June, a time which in some years predisposes crops to damage by spring frosts through flowering being too early.

In order to devise a recommended strategy to minimise frost risk in canola by sowing a cultivar appropriate to the sowing date so that flowering occurs after the main frost risk period, APSIM-Canola was coupled with long-term historical records of frost occurrence at a number of northern locations. The arrival at an optimum sowing time will depend on tradeoffs between lowered frost risk with delayed sowing and lowered yield potential and oil content. We have been able to show that it is possible to minimise frost risk to around 10% by appropriate choice of cultivar phenology for a given sowing date (Figure 19). The impact of delayed sowing on lowering frost risk in northern locations is particularly strong between mid-April and mid-May. As a result of these analyses the current recommendation is that early cultivars should be sown no earlier than the 15th May, while late flowering cultivars should be sown no earlier than the first week of May.

Working with canola growers to develop their confidence

Canola is a relatively new crop in the northern region of the wheatbelt. While many growers are trying canola for the first time they are unsure what to expect from the crop. The north-eastern wheatbelt is characterised by high rainfall variability, high temperature during grain-filling and yield-damaging frosts in spring. In addition, in contrast to southern and western Australia growing regions, winter crops in the north-eastern wheatbelt have a stronger dependence on stored soil water for growth and the importance of this for the reliability of canola production in the north-eastern wheatbelt is unknown.

Grower confidence in canola in the north has suffered at times. Problems with crop production were often cited as being due to variable climatic conditions, poorly adapted cultivars, poor establishment and inadequate nutrition. Frost at the early stages of grain-filling devastated a number of commercial crops, leading to the perception that...
canola was poorly adapted to northern climatic conditions. We have been working with established and new canola growers in the northern region in an attempt to build grower confidence in the crop. Our approach has been to intensively monitor commercial crops and identify limiting factors to yield that can be overcome with improved management. We use simulation to place the experiences of a particular paddock into a longer-term perspective. Table 42 shows results from six commercial paddocks around Moree that were monitored by us in 2002, a season with very low in-crop rain. Despite low rainfall, crops yielding over 1 t/ha were produced, largely due to good levels of available soil water stored at sowing. All crops grew to their potential based on the agreement between simulated and hand-harvested yields. The discrepancy in some cases between header and hand-harvested yields suggested yield was being lost due to harvesting losses or poor yielding sections of the paddock. Long-term simulations conducted with the growers reinforced the importance of good stored soil water at sowing to reliable yields.

The simulated median yield at Moree went from 1.1 to 2.5 t/ha as starting soil water increased from 50–200 mm. The credibility of such long-term simulations with growers is enhanced by being able to demonstrate that the model can accurately simulate yields from their own paddocks.

![Figure 19: Simulated long-term risk of sustaining a minus 1°C or minus 2°C screen temperature during early grain filling for early, mid and late flowering varieties at (a) and (b) Moree, NSW and (c) and (d) Roma, Qld.](image)

Table 42: Details of commercial canola crops monitored in the 2002 season in the Moree district.

<table>
<thead>
<tr>
<th>Farmer</th>
<th>Available soil water at sowing (mm)</th>
<th>In-crop rainfall (mm)</th>
<th>Hand harvest</th>
<th>Yield (kg/ha)</th>
<th>Potential (simulated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Deep soil</td>
<td>229</td>
<td>69</td>
<td>1610</td>
<td>800</td>
<td>1696</td>
</tr>
<tr>
<td>1 medium soil</td>
<td>140</td>
<td>69</td>
<td>635</td>
<td>400</td>
<td>845</td>
</tr>
<tr>
<td>1 shallow soil</td>
<td>80</td>
<td>69</td>
<td>466</td>
<td>140</td>
<td>555</td>
</tr>
<tr>
<td>2</td>
<td>163</td>
<td>71</td>
<td>1404</td>
<td>1500</td>
<td>1607</td>
</tr>
<tr>
<td>3</td>
<td>93</td>
<td>81</td>
<td>nm</td>
<td>1000</td>
<td>972</td>
</tr>
<tr>
<td>4</td>
<td>121</td>
<td>94</td>
<td>952</td>
<td>825</td>
<td>1154</td>
</tr>
</tbody>
</table>
Concluding remarks

Crop-soil simulation models are becoming widely used now in the arable industries of Australia, both as tools for research and development but also for advice by agribusiness and public extension programs. The canola industry has achieved remarkable gains in the last 15 years based on a comparatively small base of research and development. Simulation has the potential to add value to both agronomic and crop improvement activities by allowing extrapolation of field results beyond the specifics of particular paddocks and seasons, by highlighting research gaps, and by helping to formulate strategies for consistent production of profitable canola crops in environments with large season-to-season variability in climate.

Acknowledgement

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References


