ROBOCROP Vision Guidance System for accurate inter-row tillage in winter crops

Summary

A 6m wide Robocrop precision guided hoe was air-freighted (on loan) from Garford Farm Machinery in Britain during July, 2004, for field testing in Australian winter crops. Guidance of the hoe is achieved by real-time image analysis using a colour video camera scanning ahead of the toolbar, positioning it in relation to the crop rows using a hydraulic sideshift attached to a tractor. After assembly and commissioning, the Robocrop was demonstrated at seven sites in winter cereals - lupins, faba beans and canola at row spacings of 225mm-670mm – in Victoria (Vic) at Lake Rowan, Burramine, Birchip, Walpeup, Cobram, and Ravensworth and Oaklands) in New South Wales (NSW).

The Robocrop proved to be a robust and functional device, capable of accurately tilling in level, cultivated seedbeds. It was not suited to direct-drilled and/or stubble-retained crops. Tracking of the Robocrop guidance system proved effective in all circumstances, including under tractor lights at night. All crop stages, spacings and weed densities were tracked without apparent difficulty. Tillage accuracy depends on tractor linkage stability, skill of the operator in keeping the tractor near tramlines, matching of the Robocrop tynes to those of the drill and following the same direction of travel as the seed drill (unless it is fully symmetrical). Crop growth stage (GS) influenced tillage speed and vigour because young crops were susceptible to burial.
Conclusions

When using the Robocrop, narrow row spacings (less than 300mm) substantially reduce the proportion of tilled to untilled ground and limit forward speeds to below 5km/h, in order to prevent crop burial. Optimum row spacings to facilitate inter-row tillage in winter cereals appear to be in the range of 300-350mm. Inter-row tillage is a slow operation, compared to contemporary work rates, for crop spraying. Forward speeds are likely to be 8-12km/hr and swath width must match that of the seed drill (e.g. typically 9-18m wide). This enables spot work rates of approximately 7-22ha/hr. Fertilisation and inter-row tillage operations could be combined to assist in justifying the costs of operation.

Guidance of hooded sprayers in wide-spaced crops using the Robocrop would be feasible, but unlikely to present the advantages of introducing precision guided inter-row tillage into winter cropping systems. Preliminary economic analysis suggested that high returns on investment in Robocrop technology would result if herbicide inputs were limited using banding costs and losses in grain yield (because of herbicide resistance).

Recommendations

1) GRDC commission construction of a 6m-wide folding Robocrop ‘seed and weed’ tillage bar for evaluation by regional grower groups in each of the southern states.

2) Investigations start into optimum tyne designs for inter-row tillage at 300-350mm spacings.

3) There should be investigations into the tolerance of various grain crops to shallow burial.

Achievements/Benefits

A 6m-wide Robocrop precision guided hoe was airfreighted to Australia in fully knocked down order. It took about four days to assemble the machine ready for initial operation. All parts fitted together easily - excellent workmanship was evident. Installation of the electronics was relatively simple, with the system operational after initial booting of the computer.

A critical requirement for effective operation of a Robocrop is matching seed drill width and tyne spacing to the hoe. Originally, this was envisaged by purchase of a secondhand seed drill to sow all sites, however a late start to the project, and difficulties in locating a serviceable drill, prevented this. Subsequently, locating sites sown at 250mm spacings with tramlines in swaths of about 6m proved difficult, however seven sites were chosen for demonstration.
Various configurations of ‘A’ shares, ‘ducksfoot’ points, ‘slash’ blades and ‘bean’ knives were tested in the course of the demonstrations. Only three sites enabled comparisons to be established in statistically valid comparisons (Walpeup, Cobram and Birchip). At all other sites, full herbicide programs were applied and the demonstration served to highlight operational aspects of the Robocrop. CaseIH generously loaned a 100hp tractor fitted with row-crop wheels to assist with demonstrations. The combination of tractor and hoe was trucked from site to site.

Additional information

The following organisations and individuals provided time, finance, material and moral support to enable this initial phase of Robocrop appraisal and development to occur: Martin Blumenthal, GRDC; Phil Price, MacKeller Consulting Group; Philip Garford, Garford Farm Machinery; Nick Tillett, Silsoe Research Institute; Steve Chaffey, John Babington, Ben Jones, Vic DPI; Cherie Bell and Bobby Liston, Birchip Cropping Group; Mike Collins, Western Australian No-Tillage Farmers Association (WANTFA); Bill Long and Matt McCallum, Ag Consulting Co; Rohan Rainbow, South Australian No-Till Farmers Association (SANTFA); Bill Roy, John Holmes, Dr Steve Powles, Western Australian Herbicide Resistance Initiative (WAHRi); Greg Kautner, Australian Cotton Research Institute (ACRI); Greg Holmes (Lake Rowen), Ron Harris (Ravensworth), Chris Dowling (Burramine), Philip Kerr (Oaklands); Mark Lindner, CASE IH; Trevor Paul, Finley Machinery, and Veronique Froelich.

Discussion

Placement of a Robocrop precision guided hoe in relation to sowing swaths is more exacting than spraying because the swath must be matched with the direction of travel to accurately match tyne spacings. A visual confirmation in the form of a single navigation row, offset slightly from the tractor centreline (e.g. using a wider seed spread and/or double row) or one tramline wider than the other, would provide the visual cue to the driver about which direction he/she should be travelling.

In a cultivated seedbed with flat profile (e.g. Ravensworth using 4x375mm spaced rows of faba beans on beds) crop burial was not a problem, and bean knives or slash blades worked as effectively as ‘A’ shares. By contrast, in each instance where cereals were sown with narrow points at row spacings of 225mm-250mm, crop burial proved excessive. Soil accumulation ahead of the cultivating point was responsible for covering the crop. The widespread custom of sowing with narrow points and press wheels (but no harrows) exacerbates crop burial because inter-rows remain ridged thereafter.

Figure 1 Faba beans tolerate very few post-emergence herbicides, presenting an ideal opportunity to obtain value from inter-row tillage

‘Bulldozing wings’ could be fitted to these narrow seeding points to displace weed-rich topsoil from the intra-row. This soil can subsequently be returned to the intra-row during inter-row tillage. Seed spread in the intra-row zone should be minimised to permit a greater proportion of the paddock to be tilled. Narrow sowing points are required for this purpose.

Soil throw restrainers/crop guards are likely to be required if attempting tillage at an early GS, e.g. less than four-leaf stage for cereals) because soil throw would prove excessive unless the forward speed was reduced. Where row spacings were increased to 300mm and 325mm, clearance of soil around the point was sufficient to alleviate crop burial. It can be concluded that a minimum effective crop spacing to enable early tillage, without excessive crop burial, is likely to be approximately 300mm. Opting for 333mm would enable three tynes/m - a convenient choice in the geometry of crop spacings for controlled traffic systems. Soil displacement in narrowly spaced crops (e.g. less than 300mm) has been problematic in these demonstrations, resulting in excessive crop burial, unless tillage was delayed until advanced crop GS. In order to obtain the maximum agronomic advantage from inter-row tillage, cultivation needs to be timed early (e.g. 2-3 leaf stage for cereals).
A compromise, therefore, could be struck between row spacing, crop CS and tillage speed. A practical compromise for Australian cereal production will involve sowing crops at 333mm spacings to offer enhanced stubble flow and maximise the ratio of tilled to untilled ground, while minimising any potential loss of yield because of delayed canopy closure. Spring tynes proved inadequate for tilling compacted soils. Points would tend to ride out of the soil, collecting stubble and weeds on their leading edges and eventually causing soil to bulldoze in front of them. A spring release mechanism with high breakout resistance (e.g. 1,953kg/m²) is required if attempting to cultivate inter-rows of crops established by direct drilling.

**Figure 2** Accumulation of weeds on leading edges of tynes due to inadequate break out resistance.

Pre-sowing knockdown herbicides and/or seedbed tillage should be timed as close as is practical to sowing to enable the crop to emerge and establish ahead of germinating weeds. If a lag occurs between these operations and sowing, this enables weeds to enjoy a competitive advantage over the crop and may also lead to the crop becoming difficult to discern amid a dense and advanced population of weeds. In one instance (Cobram, barley, 5/9/04), the crop was direct drilled into a field treated about 10 days earlier with glyphosate. Rain occurred within one hour of spraying, diminishing the effectiveness of the glyphosate in removing emergent weed growth. At this site, advanced annual ryegrass dominated above the crop (1-1.5 leaf) in patches of the paddock, making the crop difficult to discern to the driver’s eye. No difficulties were encountered using the Robocrop system in these circumstances.

Tillage through retained stubble was attempted at the Walpeup site only on row spacings of 67cm. Even at this wide spacing, blockages were common, confirming that the spring tyne system, adopted by Garford Farm Machinery for their Robocrop precision guided hoe, is suited only to paddocks with no retained stubbles.

Use of trash tubes ahead of the cultivating tyne may prove desirable to enhance stubble flow during seeding and inter-row tillage operations. These devices (vertical tubes mounted ahead of the tyne) warrant evaluation. Operating a Robocrop is a fundamentally slow operation with the existing current configuration. Crop burial tends to be excessive at early growth stages, limiting forward speed to less than 8km/h. The guidance system coped adequately at 16km/h, however operator comfort was dubious at this speed and 10-12km/h is likely to prove the upper limit for Robocrop operation. Achievement of economically viable work rates will be achieved through maximising forward speeds, a wide swath (e.g. greater than 9m) and combining multiple agronomic operations in a single pass (e.g. inter-row tillage plus fertiliser banding and/or banded spraying). Forward speed and working width dictate the potential work rates for Robocrop, influencing the cost of operation of the equipment. Width will be limited to the swath of the crop seed drill because this dimension must match the width of the Robocrop toolbar. Forward speed is limited by safety, operator comfort and the amount of soil throw permissible during inter-row tillage. Soil throw can be managed by a choice of ground-engaging tools, use of soil flow limiters (crop guards), crop row spacing and speed of travel. In practical terms, 12km/h is likely to be the upper speed limit for travel and this may be much reduced when attempting to till small crops. Knife and point design will warrant investigation to minimise side throw of soil while maximising weed kill.

Mirrors are essential to enable the operator to monitor row tracking without resorting to stopping the tractor to look backwards. Instability of the tractor may have restricted the Robocrop guidance system from achieving optimal tracking accuracy.

When driving the tractor, there was a discernible sideways movement from the tractor seat associated with lateral thrust from the sideshift. This may have slowed response times in guidance, and/or over-correction of the toolbar. Sideways thrust is likely to prove more challenging as implement widths increase. Stabilising the three-point linkage of the tractor using ground engagement discs can alleviate this problem. Operation of the Robocrop at night proved encouraging because tracking appeared equally effective as during the daytime. This will enable 24-hour operation of the equipment, if required, during
periods of high utilisation.

Time of cultivation in relation to crop growth stage requires review. Many studies are likely to exist already. Investigations should be made of tolerance of various grain crops to shallow burial.

Does the exhaustion of endosperm reserves herald a reduced tolerance of burial?

Soil degradation associated with inter-row tillage should be given careful consideration. The depth and frequency of tillage, period of exposure to erosion and soil compaction will differ substantially between robotic inter-row tillage using controlled traffic vs ploughing for fallowing purposes. This differentiation between conventional tillage and delayed, or precision, tillage needs to be recognised when assessing the soil impacts of the respective techniques.

**Figure 3** Shallow precision tillage differs markedly from traditional aggressive cultivation practices.

Band spraying may be influenced by excessive cross winds. This could be alleviated by mounting nozzles low to the target (on the parallelograms) and probably inside spray or crop guards. Soil and crop conditions suited to tillage may not always coincide with calm weather for band spraying. Practical options for shielding should be explored to maximise the opportunities for concurrent band spraying and inter-row tillage.

Using the Robocrop guidance system to guide inter-row hooded sprayers was suggested by a number of growers and collaborators. There was evidence of inaccurate manual tracking of a hooded sprayer at the Walpeup site and in subsequent inspections of commercial inter-row spraying of wide-spaced crops in Western Australia (WA), suggesting that robotic guidance could play a useful role in this operation. There appears to be no practical constraint to developing robotic guided sprayers, however using glyphosate treatments in wide inter-rows (with no subsequent tillage) would impose a high selection intensity for glyphosate resistance.

**Figure 4** Shielded spraying of wheat inter-rows in Western Australia

Recommendations to alleviate this problem by using a ‘double knock’ sequence with paraquat# are unrealistic, in the view of the author, given the high cost of the herbicide (relative to glyphosate) and the inherently slow work rates achievable with inter-row spraying. Using paraquat (+/- diquat##) for hooded inter-row spraying presents another challenge over glyphosate, given the high operator hazard.

Hooded sprayers are notoriously difficult for monitoring nozzle blockages. If the sprayer is lifted during operation to view the nozzles, the operator is inevitably exposed to a hazardous spray. Occupational health guidelines are clearly compromised by this type of operation. Tillage proved highly effective with wide spacings because ample clearance exists to allow the passage of tynes and throw of soil without burying crops - there is no need to choose non-selective herbicides for this function.
Curve following with the Robocrop enabled inter-row tillage to be practised on curving headlands, around trees and where seeding has followed ground contours. This is a distinct advantage over GPS-based guidance because many instances occur in Australian grain cropping where parallel seeding of straight rows cannot be conveniently practised.

Evaluation of the agronomic performance of crops subjected to robotic inter-row tillage cannot be effectively achieved until machinery is available to overcome some of the challenges faced in this brief project. In particular, matching seed drill and tillage bar tyne spacing suggests a combination ‘seeder and weeder’ device is required of sufficient size to enable commercial tests to be undertaken. This would enable work rates and techniques to be accurately assessed. Matching seeder boots and tyne spacing to Robocrop would be assured by using the same implement for both operations.

Economic analysis comparing Robocrop to conventional broadcast herbicide applications demonstrated the key drivers to profitability using the technology. If no savings of inputs are achieved and yields remain constant, the additional capital cost of purchasing the Robocrop equipment results in a diminished net present value (NPV). Savings in herbicide input costs from banding with Robocrop show a marked improvement in gross margins. If yields of conventional crops are reduced by herbicide resistance, then Robocrop technology again demonstrated a marked increase in gross margins. Doubling fuel prices had little effect on the outcome (understandable given the low draft requirements for precision tillage). If higher grain yields are achieved (e.g. 3.5 t/ha) returns on Robocrop investment will be sooner. If herbicide inputs are reduced with banding and yield reductions because herbicide resistance is alleviated by Robocrop, there could be strong improvements. The interpretation from this analysis is that farms with existing herbicide-resistant weed populations will be likely to obtain major economic benefits from adopting Robocrop.

**Figure 6** Robocrop precision guided hoe following curved headland.

**Figure 7** Band application offers the prospect of drastically reducing herbicide inputs into broadacre cropping.
This analysis is conservative to the extent that where herbicide resistance is severe (e.g. high ryegrass populations exhibiting resistance across multiple herbicide groups) continued cropping is unlikely to be viable unless non-crop rotations are adopted to reduce weed seed burdens. Such rotations rarely generate equivalent cash returns in cereal production and, in some instances (e.g. brown manure), substantial net costs may be incurred. Continuous cropping may be more viable in these circumstances, by the adoption of inter-row tillage and improved nitrogen utilisation from timely and accurate in-crop, tactical fertiliser applications. It could also serve to lift grain yields above those of conventional practice.

Economic evaluation

Table 1 Simulated impact of Robocrop-guided operations on economic performance indicators of a grain farm producing 2,000ha of cereals with an average yield of 1.8t/ha.

<table>
<thead>
<tr>
<th>Scenario Analysis</th>
<th>Gross margin difference - (Robocrop vs Conventional)</th>
<th>Net Present Value</th>
<th>Internal Rate of return</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Base case - Yield, herbicide inputs &amp; fuel price the same</td>
<td>-7%</td>
<td>-$279,071</td>
<td>n/a</td>
</tr>
<tr>
<td>2 Herbicide inputs banded to 30%</td>
<td>8%</td>
<td>-$61,327</td>
<td>3%</td>
</tr>
<tr>
<td>3 Yield of conventional crop reduced by 10% because of resistance</td>
<td>13%</td>
<td>-$34,696</td>
<td>7%</td>
</tr>
<tr>
<td>4 Fuel price increased by a factor of 2</td>
<td>-9%</td>
<td>-$296,993</td>
<td>n/a</td>
</tr>
<tr>
<td>5 Scenario analysis – combining scenarios 2 &amp; 3.</td>
<td>32%</td>
<td>$183,048</td>
<td>35%</td>
</tr>
<tr>
<td>6 Scenario analysis – combining scenarios 2, 3 &amp; 4.</td>
<td>32%</td>
<td>$165,126</td>
<td>33%</td>
</tr>
</tbody>
</table>

Refer to Attachment 1

Required rate of return for NPV calculation was 12%.

The economic modelling of Robocrop, compared to conventional cropping methods, is a preliminary analysis based on information known or assumed at December, 2004. Further work to confirm various economic variables will increase the level of trust in the data provided. The modelling is designed to allow all the variables to change to detect their effect on the critical performance measures of gross margins and NPVs. This economic modelling is a capital budgeting exercise where capital is invested in the initial years, affecting cash inflows and outflows from farm businesses.

The modelling makes a number of assumptions:

1) The comparison includes conventional operations from the time of sowing to the final in-crop operation, e.g. sowing, spraying and fertilising. The assumption is that operations before sowing and after the last in-crop operation will not affect...
the comparative economics of Robocrop compared to conventional sowing, spraying and fertiliser operations.

2) The economic analysis for Robocrop includes a gross margin assessment and projected cash flow over 10 years where the first year accounts for the initial investment and the remaining nine years for operating cash flows.

3) The tractor specifications assumed in the modelling are 141kW PTO (190hp) and 148kW engine (225hp). Example tractors: John Deere 8220, Case Magnum MX220. Reference: ‘NSW DPI Guide to tractor and implement costs’.

4) The model assumes the farm business would crop 2,000ha of winter cereals (wheat) each year in which Robocrop would be used. It does not include other crops as part of the analysis.

5) It is assumed that a 12% required rate of return is expected from the calculation of NPV.

6) Depreciation of equipment is included.

7) In-crop fertiliser could be urea or urea liquid nitrogen (UAN), e.g. topdressing with urea 50-100kg/ha with one application at the tillering stage costing approximately $460/t; foliar application with UAN, 20-40L/ha with one to three applications - could be mixed with herbicide - for approximately $455/t bulk.

8) The cash flow assumes variables, such as yields, remain the same over time. In reality, yields may behave differently, declining on an increasing basis because of herbicide resistance. This behaviour is not captured by the model.

A scenario analysis is provided, allowing comparisons of one or more variable effects on the key performance indicators used in the model.

**Fuel consumption**

Monitoring of fuel consumption was conducted in three runs on 21/10/04 at the Cobram site. Soil moisture was low, with the ground hard and deeply fissured. Barley was at the booting stage.

Ground engagement was made using a mix of flat ‘A’ and ducksfoot shares.

<table>
<thead>
<tr>
<th>Run</th>
<th>Area (ha)</th>
<th>Engine Revolutions (Rpm)</th>
<th>Speed (Km/hr)</th>
<th>Fuel consumed (Mls)</th>
<th>Fuel consumed (l/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.55</td>
<td>1200</td>
<td>7</td>
<td>800</td>
<td>1.45</td>
</tr>
<tr>
<td>2</td>
<td>0.54</td>
<td>1400</td>
<td>8</td>
<td>900</td>
<td>1.66</td>
</tr>
<tr>
<td>3</td>
<td>1.04</td>
<td>1600</td>
<td>10</td>
<td>1600</td>
<td>1.54</td>
</tr>
</tbody>
</table>

These figures are very similar to those recorded at Silsoe Research Institute in June, 2004, using a 12m wide experimental Robocrop precision tillage bar.

**Economics evaluation**

Any detailed analysis of the economics of inter-row tillage with Robocrop is limited by an absence of agronomic performance data. Some broad assumptions can be made, however, to investigate the likely commercial viability of the technique.

Attachment 1 presents an economic analysis comparing Robocrop inter-row tillage of wheat vs conventional (broadcast herbicides). Comparison has been restricted simply to sowing and post-sowing weed control operations on a 2,000ha cropping operation using a theoretical implement that would be capable of seeding and inter-row tillage operations.