Frontiers of farm productivity: using more of the soil and more of the season

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Abstract

Integrating long-season wheat and canola crops in a crop sequence can significantly increase farm productivity and profitability through higher yield potential, improved timing of the whole-farm sowing program, and through grazing. However deep soil water use of higher-yielding crops can leave a legacy of dry or N-depleted soil that may impact subsequent crops, and reduce the expected yield benefits across the crop sequence. We used the APSIM model, validated against 30 years of measured data from a long-term field experiment at Harden in NSW to explore the legacy effects and overall impact of incorporating long-season wheat and canola crops into the cropping system at Harden in southern NSW. APSIM predicted dynamics of water, mineral N, biomass and yield adequately across the continuous 30-year sequence, providing confidence in the ability to explore modified management scenarios. At Harden, we predicted opportunities to increase mean wheat yield (22%) and canola yield (14%) using early-sown, long-season varieties compared to faster-maturing spring varieties sown in May, in seasons where early sowing (from March 1) was possible. The yield improvements increased to 33% for wheat and 72% for canola when an extra 50 kg N/ha was top-dressed each season demonstrating the importance of matching N supply to the higher yield potential of the crops. The continuous simulation revealed legacy effects were evident in some seasons, but were small overall, at least in this high rainfall environment. The approach can be applied elsewhere, but relies on well-validated, continuous simulation of the crop sequence, which are rare.

Key Words

early sowing, water use, wheat, canola, nitrogen, farming system, root depth

Introduction

In recent years, farms have adapted to the impacts of climate change and to increasing farm size by moving crop sowing times earlier, with slower-maturing crop varieties that flower in optimal windows can increase yield potential (Hunt et al. 2019, Flohr et al. 2018, Kirkegaard et al. 2016). Whole farm productivity can be increased significantly by opportunities to start sowing earlier due to the flow on effects to the whole sowing program (Hunt et al. 2019). The benefit to whole farm production varies significantly in different regions, related to the frequency of sowing opportunities, to soil depth and to the ability in different regions to capitalise on higher yield potential. In general, benefits were greater in southern and Western Australia and in higher rainfall areas. On mixed farms, these early sown cereal and canola crops can also be grazed, providing further opportunities to increase farm productivity and profitability, and to manage risk (Dove and Kirkegaard 2014). A significant part of the benefit of early-sown crops is that the longer vegetative phase leads to deeper rooting and access to deep water and N late in the season during grain-filling (Kirkegaard et al. 2015, Flohr et al. 2019). The question then arises about the long term cumulative effects on water and N use – i.e. how often will deep water (>1m) be available across a sequence following its use by higher-yielding, longer-season crops? (Lilley and Kirkegaard 2016, Thorup-Kristensen and Kirkegaard 2016). We explored this question using the APSIM model validated using data from a long-term field experiment, and run continuously to allow investigation of legacy effects.

Methods

Harden long-term field experiment

A long-term tillage experiment established at Harden in NSW in 1990 and cropped to the present day was used as a source of data in the study (Kirkegaard et al. 1994). The treatment involving a late stubble burn (April) and single cultivation prior to sowing was selected for this study as it was least affected by foliar diseases and frost during the study period. A break-crop/wheat sequence was grown for the first 16 years (including 3 canola, 3 lupin and 2 field pea crops), but two 3-year wheat sequences were grown during dry period from 2007-2013, separated by 1 canola crop. Recommended spring varieties of each crop were successfully established in mid-late May in all seasons, and were managed with good agronomy to control weeds, disease and ensure no significant nutrient deficiencies affected productivity. Starting soil water and mineral N were measured to 1.6m using 4cm diameter soil cores prior to sowing and at harvest intermittently throughout the crop sequence. Plant available water content of the soil profile to a depth of 1.6 m was 169 mm. Crop measurements in all years included plant density, flowering and maturity biomass, yield and yield components and grain protein using cut and dried samples from bordered quadrats ($2m^2$) and plot harvesters. These measured data were used to test the capacity of the APSIM model to accurately simulate soil water and N dynamics, and crop production at the site prior to the simulation study to predict the impact of agronomic interventions.

Simulation - validation

In 2004, the APSIM model was validated against the first 13 years of data in a study investigating the risk of water and N leaching under no-till farming at the site (Lilley *et al*. 2004). In this paper we have updated the simulation to include all years up to 2016. APSIM version 7.9 was used to simulate the crop sequence using wheat, canola, lupin and field pea modules with cultivars selected according to observed phenology events. Sowing, harvest and N application dates and rates were simulated according to field operations. Meteorological data were extracted from the SILO Patched Point Dataset (Jeffrey *et al*. 2001). Weeds were simulated by assuming germination occurred if there was no crop growing and rainfall on two consecutive days exceeded 25 mm. This followed a rule by Fischer *et al*. (1990). The Weed module was set to grow a late winter grass at a density of 15 plants m^{-2}. Weed death was simulated on dates corresponding to the actual spraying, burning or cultivation operations in the field experiment. Soil N mineralisation rates were set according to the rates described for southern NSW by Snow *et al.* (1999). The simulation was set up to begin on 1/2/89 before the oat crop was sown in March. Surface residues were estimated to be 1 t/ha with a C:N ratio of 30. Pasture root biomass was set at 5 t/ha with a C:N ratio of 40. The soil organic carbon profile was set to match that reported by Kirkby *et al*. (2016) including the humus pools. To achieve this Fbiom was initialised at 0.05 throughout the profile and Finert at 0.01 from 0-05 m, 0.1 from 0.5-1 m and 0.25 below 1 m. Soil water and mineral N profiles were reset to actual values using the sampling of the soil at sowing of the 1990 wheat crop. The model was then run continuously for 28 years without any further resetting. Predicted levels of biomass, yield, soil water and N profiles were compared with measured values.

Simulated impacts of agronomic interventions

Following the validation of the measured data, we simulated the impact of a series of sequential changes to crop management to investigate the predicted impact on crop yield and legacy effects. These included: (1) Strict summer weed control: In the experiment we targeted strict summer fallow weed control but in a few seasons control was not ideal. The first intervention assumed perfect summer weed control from harvest to sowing of the subsequent crop in all years. (2) Earlier sowing with appropriate varieties: We used the actual rainfall data from the site each season to identify the first sowing opportunity after 1 March, and simulated the sowing of suitable varieties to maintain optimal flowering. Firstly we sowed early wheat only, and then sowed both wheat and canola early according to the sowing opportunities. We were able to investigate the impacts of earlier sowing of either wheat, or wheat and canola, on the yield of each crop over the entire sequence to identify any legacy effects due to either reduced water or N availability. (3) Additional N: The higher yield potential of earlier-sown crops was likely to increase the demand for N so for the current analysis we simply applied an extra 50 kg N/ha as a top-dressing at the time of stem elongation in both wheat and canola to investigate the impact of higher N supply on predicted yield.

Results

The measured and simulated soil water, mineral N, crop biomass and yield for the full sequence from 1990 to 2016 are shown in Figure 1. The model was able to predict soil water well (RMSE=32 mm; range 243 mm to 468 mm) with only isolated cases (e.g. summer 1995) where agreement was poor. The soil mineral N predictions were also very good (RMSE 50 kgN/ha; range 61 to 317 kgN/ha), with a tendency to under-predict somewhat during the earlier years but with increasing accuracy over time. As a consequence of good predictions of both soil water and N, both the crop biomass (RMSE 1.5 t/ha; range 0.1 to 20.1 t/ha) and yield (RMSE 0.8 t/ha; range 0.6 to 8.0 t/ha) simulations were also very good with only a few cases where the model under-predicted yield (e.g. 2001, 2004 and 2012). To our knowledge this is one of the first and most extensive validated data sets run continuously using APSIM across a diverse cropping sequence.

In the simulation of scenario, sowing dates for the wheat and canola generally moved from May back to March or April as a result of the frequent early sowing opportunities that occurred in Harden during the course of the experiment. Some interesting legacy effects occurred throughout the sequence. For example sowing wheat early in 2009 (16 March instead of 1 June) increased wheat yield in that year by 1.5 t/ha (from 3.4 to 4.9 t/ha), but this reduced the yield of the subsequent spring canola crop in 2010 by 0.9 t/ha (from 3.1

t/ha to 2.2 t/ha). The canola yield was surprisingly unaffected by sowing canola earlier in 2010, possibly suggesting water was limiting yield levels in that year. However both the legacy effect and the canola yield reduction disappeared when an extra 50 kg N/ha was applied suggesting N, rather than water was limiting the canola yield and causing the legacy.

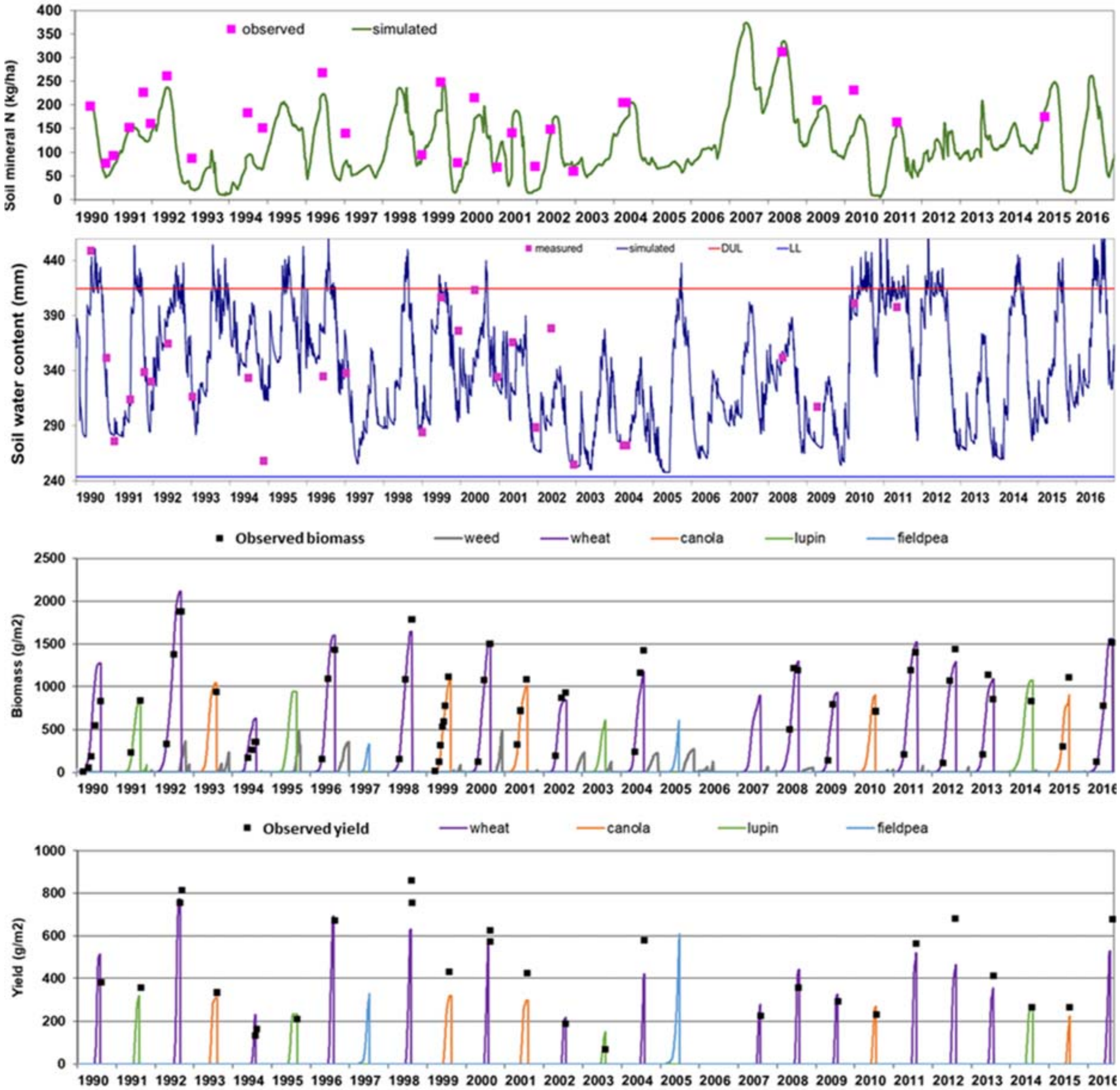

Figure 1. Observed (points) and simulated (line) soil mineral N (kgN/ha; 0-160 cm), soil water (mm; 0-160 cm), crop biomass (g/m^2) and grain yield (g/m^2) for the sequence of crops grown at Harden (1990-2016). Red horizontal line shows drained upper limit (DUL), blue horizontal line shows lower limit (LL).

This example of a significant legacy was relatively rare across the sequence, as demonstrated in the mean impact of the sequential changes in management to crop yields across the sequence (Table 1). Summer fallow weed control gave a relatively small yield increase to both crops as the actual weed management was good. Earlier sowing of wheat increased mean wheat yield by an average of 0.9 t/ha, but reduced canola yield by 0.2 t/ha, due to legacy effects of the higher-yielding wheat. Sowing canola early as well as wheat provided a boost to average canola yield, with only a small reduction in wheat yield. Increasing the N supplied to crops each year by 50 kg N/ha increased the mean yield of both crops overall, but especially canola, suggesting N limits early-sown canola yield at the site. The predicted yield of wheat with additional N decreased in 2002, 2012 and 2013 (data not shown) presumably due to haying-off in the wheat year, rather than a legacy of higher yield by preceding crops, but both mechanisms in a crop sequence.

Table 1. The predicted impacts of sequential changes to management on the long-term mean yield of wheat and canola (t/ha) at the Harden long-term tillage site.

Crop	Baseline (measured)	Weed Control	Weed Control Early wheat	Weed control Early wheat Early canola	Weed control Early wheat Early canola +50 kg N/ha/yr
Wheat	4.5	4.7	5.6	5.5	6.0
Canola	2.9	3.1	2.9	3.3	5.0

Conclusion

The simulation has confirmed significant potential to increase yield at this site by including early sown wheat and canola varieties, but increased N supply was critical to achieve the higher yield potential. Despite legacy effects in some seasons, the long-term impact of adopting this package of innovations was to increase wheat yield by 33% and canola yield by 72%. Further refinements are likely with tactical approaches from year-to-year based on decision rules to minimise legacy effects. In drier environments, the legacy effects are likely to be larger, and this can be investigated using the validated simulation approach used here to identify circumstances where significant legacies may negate the benefits of earlier sown crops. Careful validation against field data using continuous runs is required to provide more confidence in the predictions, to better target subsequent agronomic research to test the most promising innovations.

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