Estimated long-term trends in agronomic strategies for mitigating competition in companion cropping systems

Rob Harris[12], Don Gaydon[3], Bill Bellotti[4], Murray Unkovich[2] and Mike Robertson[5]

[1]Department of Primary Industries Victoria, Hamilton Vic 3300, www.dpi.vic.gov.au Email rob.harris@DPI.vic.gov.au
[2]School of Agriculture, Food and Wine, University of Adelaide, Waite SA 5064, www.adelaide.edu.au
[3]Commonwealth Scientific and Industrial Research Organisation, Sustainable Ecosystems, St Lucia QLD 4067, www.csiro.au
[4]School of Natural Sciences, University of Western Sydney, Richmond, NSW, 2753, www.uws.edu.au
[5]Commonwealth Scientific and Industrial Research Organisation, Sustainable Ecosystems, Wembley WA 6913, www.csiro.au

Abstract

The simulation model APSIM (Agricultural Production Systems Simulator) and a long-term (1956-2007) climatic dataset was used to study competition in cereal sown into lucerne to assess the role of agronomic strategies for mitigating wheat productivity losses in polyculture. Simulations were performed for wheat growing with (companion crop) and without (cereal monoculture) lucerne under historical rainfall on a red sodosol soil in NE Victoria. In both monoculture and companion crop simulations wheat received N fertiliser at 0, 30, 60 or 90 kg N/ha, with and without pre-crop suppression of lucerne for each rate of N application in the companion crop simulations. Across the time series, on average the cereal monoculture had an extra 81 mm of plant available water at sowing compared with that under companion cropping. Competition for available soil water appears the likely cause for lower companion cropped cereal yields prior to cereal stem elongation in field studies. Companion cropping yield was strongly influenced by the amount of in-crop rainfall. Growing season rainfall (GSR) with a decile of 3 or less (≤298 mm), resulted in estimated mean grain yield reduction of 1860 kg/ha in companion cropped cereal compared with the cereal monoculture. When GSR was decile 4 (≤299 mm) or greater, the estimated mean difference in grain production between the cereal monoculture and companion cropped wheat was 932 kg/ha. Simulations also showed that the combination of pre-crop suppression of lucerne and additional fertiliser N, improved companion wheat utilisation of in-crop rainfall compared with companion wheat growing in the absence of these mitigation strategies.

Key Words

Wheat, lucerne, simulation, APSIM, model.

Introduction

Lucerne Companion cropping is a practice where annual crops are sown directly into existing lucerne (*Medicago sativa*) stands; and is one approach available to farmers for integrating lucerne into cropping systems. Perennial herbaceous plants like lucerne offer greater year round plant transpiration, whilst maintaining farm income compared with annual pastures grown in rotation with annual crops. Increasing the water use of farming systems is a key strategy for reducing the impact of agriculture on the surrounding landscape, by either using rainfall when and where it falls, or by increasing the soil's capacity to store excess rainfall for deferred subsequent plant use (Dunin *et al*. 1999), reducing water leakage below the root zone. Water escaping from the root zone can contribute to land degradation, such as dryland salinisation and soil acidification. Furthermore, cereal crops sown into established lucerne could provide dual income streams to mixed farming systems through grain production and provision of better summer and autumn feed for livestock.

Whilst companion cropping offers many advantages, companion cereal yield reductions associated with competition from neighbouring lucerne, has often been a major constraint (Egan and Ransom 1996; Humphries *et al*. 2004). Past field research has attempted to identify the key factors driving competition

(Egan and Ransom 1996; Harris *et al*. 2008a), but there is still uncertainty regarding the specific mechanisms. Recent research has shown that under some circumstances agronomic intervention can mitigate competition and produce more favourable outcomes for companion cereal performance (Harris *et al*. 2007). However, these findings have been confined to a limited number of seasons, and questions remain regarding what drives competition, and how agronomic strategies for mitigating competition might perform under a broader range of climatic conditions. Recent developments in computer crop modelling provide opportunities to explore cereal and lucerne interactions over many seasons, to examine how the severity of competition is affected by resource supply, and how agronomic strategies might alter resource capture to produce more productive companion cereal crops.

The computer crop model APSIM (Agricultural Production System Simulator) has been used for extrapolation of findings beyond season and site specific field based research (Asseng *et al*. 1998). The model can simulate interactions between climate, soil and plant growth, while providing the flexibility to stipulate specific management strategies that can affect these interactions. Recent research has validated APSIM's capacity to simulate competition in companion cropping systems throughout southern Australia (Robertson *et al*. 2004; Harris *et al*. 2008b), largely reporting satisfactory model performance. This paper compares simulated wheat production in the absence and presence of lucerne over 51 seasons, to understand why yields of companion cereals are often lower than cereals growing in monoculture. Additional data from long-term simulations are then used to explore trends in companion cereal responses to lucerne suppression and N fertiliser strategies; to determine if, and under what circumstances these strategies might mitigate competition, and increase companion cereal yield.

Methods

This paper represents results of long-term simulations of cereal and lucerne growth on a slightly acidic (pH 6.4 in $CaCl_2$, 0-12 cm) Red Sodosol soil (Isbell 1996) in north east Victoria. Climatic data was sourced from the SILO database (http://www.bom.gov.au/SILO) for the Peechelba East (146^{o}27'E, 36^{o}17'S) weather station, located approximately 7 km south of the field experiment reported in Harris *et al*. (2008a). In our study APSIM was configured to perform two simulations; wheat grown in monoculture (cereal monoculture), and wheat and lucerne grown together (companion crop). In both the cereal monoculture and companion crop simulations wheat received N fertiliser at 0, 30, 60 or 90 kg N/ha, top-dressed at 40 d post sowing. Additional companion crop simulations were performed, where each rate of N application received simulated +/0 pre-crop suppression of lucerne growth. The long-term simulations of cereal biomass and grain yield in response to agronomic strategies (lucerne suppression and N rate) were then used to identify the optimally performing cereal monoculture and companion crop simulations.

Long-term simulations using APSIM5.3 used the same modules described in Harris *et al*. (2008b) for the cereal monoculture and companion cropping systems. Model parameterisation remained the same as detailed by Harris *et al*. (2008b), except that sowing of cereal crops with fertiliser N, and pre-crop suppression of lucerne were performed when cumulative rainfall was >15mm over a 10 d period between 15 April and 7 July. The wheat cultivar Diamondbird was sown in all years of the cereal monoculture and companion crop simulations, at a plant density of 170 plants/m^2. Coincident with sowing in the companion crop simulations, lucerne was suppressed by using the management logic module to cut lucerne to ground level, but not remove biomass, and then setting lucerne radiation use efficiency (rue) to 0 for a 14 d period, to emulate the use of herbicide to suppress lucerne growth in the corresponding Harris *et al*. (2008) field experiment. Top-dressed N was applied as urea at 30 kg N/ha (30N), 60 kg N/ha (60N) and 90 kg N/ha (90N) at 40 d after sowing. Simulations commenced on 1 August 1955 shortly before establishing lucerne cv. Kaituna, at 150 stems/m^2 in the companion crop simulation. A fallow period was simulated in the cereal monoculture before crops were sown in the autumn of 1956 in both the cereal monoculture and companion crop simulations. All simulations ended on 31 December 2007. Plant available water content (PAWC) was 119 mm to a depth of 1.1 m for wheat and 155 mm to a depth of 2.7m for lucerne. Soil mineral N(NO_3^- and NH_4^+) in all simulations was reset every 2nd year on 25 April, to maintain soil N at levels observed in the corresponding Harris *et al*. (2008a) field experiment. Both the cereal monoculture and companion cropping systems received simulated grazing over the summer periods on 15 January, 1 March, 15 April and 11 December. Both systems were grazed to a height of 20 mm.

Results

In all years, the companion cereal crop produced less biomass compared with the cereal monoculture (Figure 1a) with a mean biomass difference of 3799 kg DM/ha. Simulated grain yield showed a similar trend (Figure 1b) with the mean yield difference between the companion crop and the cereal monoculture of 1489 kg/ha. Simulated plant available water (PAW) at sowing of the cereal crop, was always lower under companion cropping, compared with cereal grown in monoculture (Figure 1c), on average the cereal monoculture had an extra 81 mm of PAW at sowing.

The difference between simulated cereal grain yield growing with and without lucerne was greater under less favourable growing season rainfall (April to October rainfall, Figure 1d). Under low rainfall conditions (Decile 1 to 3, 145 – 298 mm of GSR) long-term mean grain yield was reduced by 1860 kg/ha in the companion crop compared with the cereal monoculture, whilst under favourable growing conditions (decile >3, >298 mm of GSR) long-term grain yield was reduced by only 932 kg/ha in the companion crop compared to the cereal monoculture (Figure 1d).

(a) (b)

(c) (d)

(e) (f)

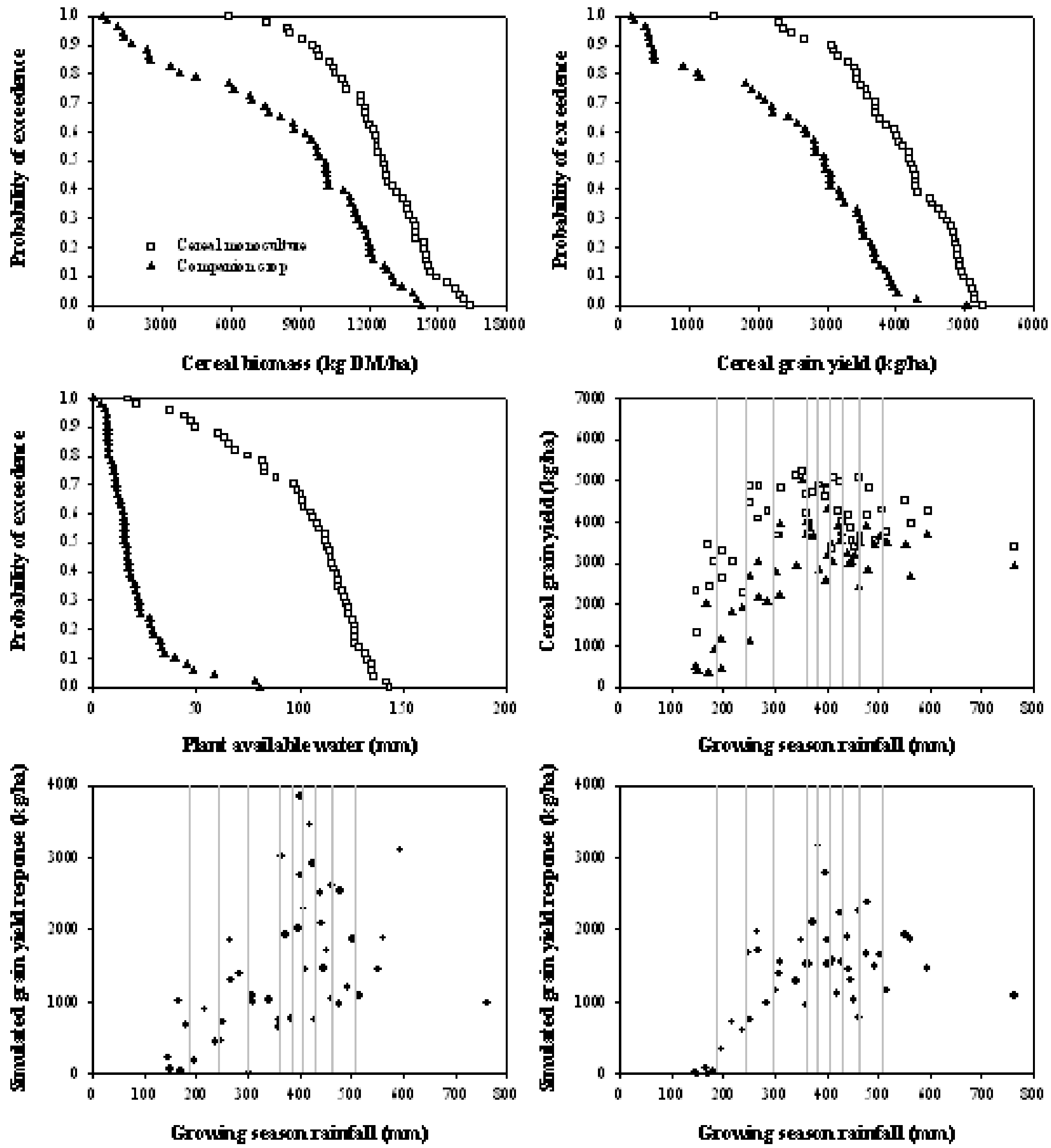

Figure 1. Simulated long-term (1956-2007) cereal biomass (a) and cereal grain yield (b) for cereal grown with and without lucerne, and the long-term effect of the cereal monoculture and companion cropping treatments on plant available water in the top 1.1 m of the soil profile at cereal crop sowing (c); Simulated long-term grain yield growing with and without lucerne (d); and companion cereal grain yield response to pre-crop suppression of lucerne with N (mean of all rates of N) (e) and without top-dressed N (f) in response to different quantities of growing season rainfall (April to October). Vertical lines represent the boundary for each GSR decile.

Simulated pre-crop suppression of lucerne and top-dressed N resulted in a more pronounced relationship between GSR and companion cereal grain yield (Figure 1e and 1f). Although the relationship tended to plateau once GSR exceeded 350 mm, particularly the response to N fertiliser. The spread of responses at similar growing season rainfall may be a reflection of both the amount and distribution of in-season rainfall.

Discussion and conclusion

The availability of stored soil water at sowing appears to play a major role in competition between the companion cereal and lucerne. Long-term simulations showed consistently less stored soil water at sowing under companion cropping, compared with cereals grown in monoculture. Lucerne growth over the preceding summer largely depleted the soil profile of moisture, prior to planting the companion cereal. Therefore, the severity of competition between the companion cereal and lucerne appears strongly influenced by the quantity of in-crop rainfall. Thus companion cropping would not be suitable in environments where crop yield relies on stored soil water. Many studies have reported reductions in companion crop productivity in the presence of lucerne, compared with cereal grown in monoculture (Egan and Ransom 1996; Humphries *et al*. 2004; Harris *et al*. 2007; Harris *et al*. 2008). Companion crop productivity is compromised early in the growing season prior to stem elongation (Harris *et al*. 2007; Harris *et al*. 2008a). Harris *et al*. (2008a) showed that cereals growing with lucerne produced fewer tillers and consequently lower cereal biomass compared with cereals in monoculture. Other studies have shown a link between early vigorous cereal growth and greater subsequent grain yield (Palta and Fillery 1995).

The combination of pre-crop suppression of lucerne and N fertiliser can improve companion crop performance, but the success of these strategies appears dependant on the quantity of in-crop rainfall. In the absence of pre-crop suppression of lucerne, competition for light early in the growing season could be a contributing factor in determining the companion cereals dominance, over the neighbouring lucerne component. Canopy height will dictate which component can utilise the majority of resources (water and nitrogen) on offer thereafter.

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