The development of a wild oat simulation model for APSIM

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Summary In this paper we describe preliminary investigations into the development of a wild oat model that can be integrated into the APSIM modelling framework, with the aim of simulating crop weed interactions. This paper describes the initial development of the wild oat model and shows validation results against experimental data. The paper then explores the possibilities of using a wild oat model to understand weed competition and climate variability within a farming system context.
Keywords Chickpea competition, modelling simulation, wild oat.

INTRODUCTION

Wild oat is one of the most prolific grass weed species in the Australian grains regions; it is certainly considered the most prolific weed in the northern grains region (Martin *et al.* 1988, Felton 1995, Jones *et al*. 2000). Two species of wild oat predominantly occur on the grain farms of Australia. *Avena fatua* tends to dominate the southern and western grains regions, while *A. sterilis* ssp. *ludoviciana* dominates the northern grains region. Despite this separation both types can generally be found in all Australian grain regions. A national survey of grain producers by the chemical company Hoechst Australia (now AgrEvo), found that wild oat occurs on two out of three farms in the winter cereal grains regions (Medd 1997). As a result of this high profile, wild oat is one of the most researched weeds in eastern Australia.

The competitive effect of a weed on the yield of a crop is often described by a hyperbolic relationship between crop yield and weed density (Kropff and Spitters 1991). Static representations of competition using such curves are unable to convey the influence of factors such as season-to-season variation on the degree of competition between crop and weed. Computer simulation models that can cope with weed-crop competition can be used to predict the effect of different weed densities on crop production and the interaction with seasonal variation. Once validated, outputs from these models can be used to assess the range of tactics making up integrated weed management systems, and potentially assist in design of improved management systems.

This paper reports the preliminary development of a wild oat module for the cropping systems model APSIM, and its ability to simulate potential yield loss when grown with the existing APSIM-chickpea-model. We tested the model on a detailed experiment conducted during the winters of 1996 and 1997 at Warialda NSW in the northern grains region of eastern Australia, and then show, using simulations with historical climate data, and the expected impact of seasonal variability on the competitive effect of wild oat grown in competition with chickpea using conventional weed yield loss modelling methods.

MATERIALS AND METHODS

Model development and testing APSIM simulates competition for light in a species mixture by taking account of the differential height and leaf areas of the different species (Carberry *et al*. 1996). Competing canopies are assumed to be well-mixed in the horizontal dimension. Competition for water and nutrient uptake is calculated by allowing the roots of each species to have preferential access to soil resources in a day-by-day rotation with the other competing species.

Wild oat was assumed to grow with similar growth and development parameters as the APSIM Wheat module, with some minor adjustments. Wild oat was parameterised from the APSIM wheat module using the crop template method described by Robertson *et al*. (2002). The main parameter adjustments were to over-top the chickpea later in the season (Weaver *et al*. 1993) by altering the relationship between stem mass per plant and plant height. The rate of leaf development was also increased to achieve observed early biomass measurements and time to anthesis. The phenological changes were consistent to those reported for *A fatua* by Weaver *et al*. (1993). Being a preliminary model and due to insufficient observed data at the time of development, no change was made to the maximum harvest index of wheat. It is acknowledged that wild oat would have a poorer partitioning to seed than wheat so no weed seed yield results are presented.

The model was tested on an experiment conducted at Warialda (Whish 1999), that measured the effect of a range of wild oat densities (0, 2, 4, 8, 16 and 32 plants m^{-2}) on chickpea yield. Yield reduction of chickpea varied from none to >90% and so gave a good range of competition intensity with which to test the model. A self-mulching black Vertosol parameterised at a close-by site was used to represent the soil on which this experiment was located

Initial runs of the chickpea model gave yields close to those observed in the weed free controls of the experiments for the 1996 and 1997 seasons. So it was assumed that soil-starting conditions had been parameterised correctly.

Long-term simulations Simulations using daily climate data for Warialda, for the period 1957 to 2001 were conducted using the experimental treatments imposed in the experiment of Whish (1999). The simulation set-up (sowing dates of crop and weed, densities of crop and weed, and soil parameters) were the same as in the model validation exercise and reflected actual field activities. Soil water and nitrogen contents at sowing of the chickpea crop were the same in each season, so that the resulting variation in competition with wild oat was an outcome of seasonal conditions following sowing.

Output from the simulations was analysed using the statistical yield loss model of Cousens (1985), (Eqn. 1).

$$Y_L = \frac{Id}{1 + \frac{Id}{A}} \qquad \text{(Eqn. 1)}$$

Y_L: percentage of yield lost because of weed competition
d: weed density
A: percentage yield loss as d→∞
I: percentage yield loss per unit weed density as d→0

The key parameters in the equation describing the curve are:

A– the percentage crop yield loss at very high weed density, and

I – the percentage crop yield loss per unit weed density (plants m^{-2}) at very low weed density.

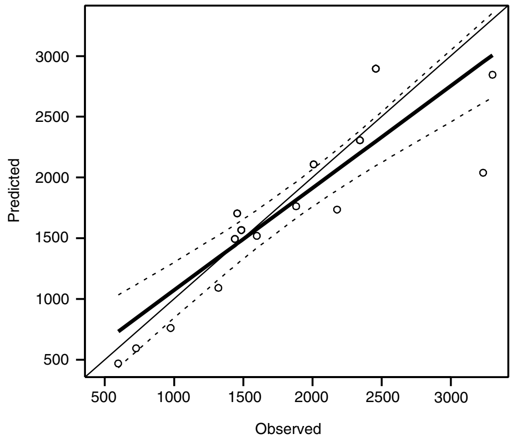
A curve relating chickpea yield loss from the weed-free situation to weed density was fitted to derive values of A and I for each season.

RESULTS

Model testing Figure 1a and b show that the model is capturing the effects of weed density on chickpea grain yield and biomass

There was a reasonable simulation of weed biomass across the five density treatments (Figure 2), although the model appears to over predict biomass in the low yield treatments and under predict biomass in the higher yield treatments. Under prediction by the model suggests a problem with the availability of resources, either from the initial setting of the system or by the chickpea capturing to higher proportion of the available resources. In this case the initial set up of the model is unlikely to have been limiting. In parameterising the wild oat model from a wheat

(a) chickpea yield (kg ha^{-1}).



(b) chickpea biomass (kg ha^{-1}).

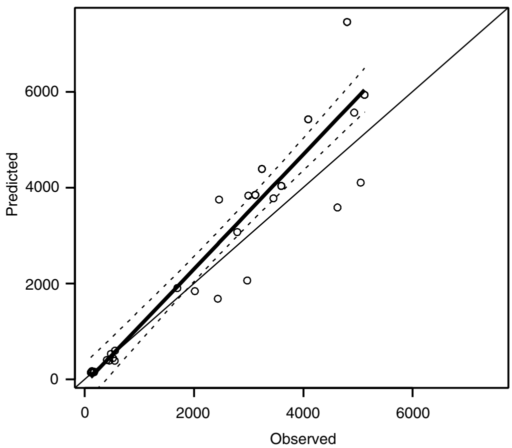


Figure 1. Overall agreement between observed and simulated chickpea yield (a) and biomass (b) as a result of competition with wild oat. Each point is from an individual density treatment. The 1:1 line is plotted, with a linear regression through the points R^2 for chickpea yield = 0.76 and biomass = 0.89. Broken lines represent the 95% confidence interval.

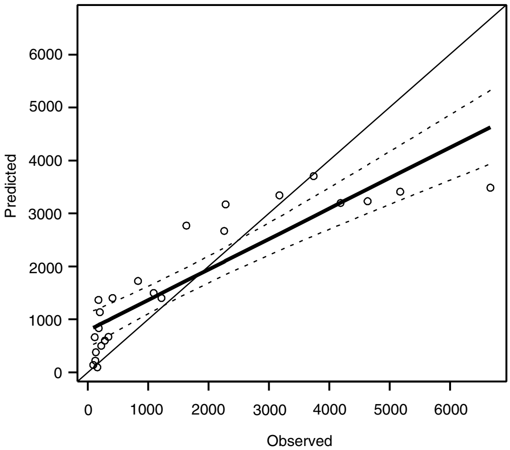


Figure 2. Overall agreement between observed and simulated wild oat biomass (kg ha^{-1}) as a result of competition with chickpea. The 1:1 line is plotted, with a linear regression through the points R^2 for wild oat biomass = 0.78. Broken lines represent the 95% confidence interval.

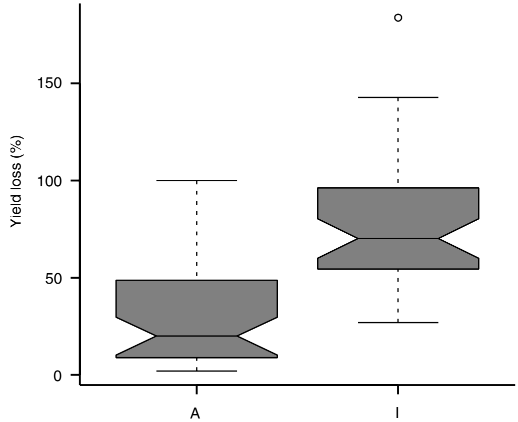


Figure 3. Variation observed in the *A* and *I* parameters of a rectangular hyperbolic model when applied to 43 years of simulated yield loss and weed competition data.

model the ability to extract soil water was not changed, Pavlychenko and Harrington (1935) showed wild oat when compared to wheat developed a more extensive root system, and this may explain the potential limit on wild oat biomass when grown with chickpea as observed in these simulated trials.

Long term simulations Long-term simulation of wild oat emerging with chickpea at Warialda over 43 years produced the expected, typical hyperbolic shaped curve between crop yield loss and weed density. Variation among seasons in the initial slope and asymptote of the curves indicate seasonal variation in the parameters A and I. This seasonal variation was summarised using box and whisker plots (Figure 3). The box indicates the inter-quartile range and the whiskers are 1.5 times the inter-quartile range. Points outside this are displayed individually. In fitting the hyperbolic model to the simulated results from each individual season no constraints were applied to the A and I parameters, so on occasions the parameters exceeded 100%. This shows that under specific climatic conditions the high densities are insufficient to create an asymptote, and highlights the importance of seasonal variation on competition between chickpea and wild oat. The curves in some seasons were linear over the range of weed densities simulated, rather than hyperbolic which also identifies the influence of season on competition, and shows how static models can significantly underestimate the degree of competition between crops and weeds during specific seasons.

DISCUSSION

The work reported in this paper is a preliminary investigation of integrating simulation modelling of competition between chickpea and wild oat using APSIM with conventional crop yield loss modelling methods used by weed scientists. The development of an APSIM-wild oat module still requires work and validation under a range of environments. However, even using this preliminary model the shortcomings of developing relationships between weed density and crop yield loss by relying on experimental data from one or two seasons are obvious. An approach using a validated crop-weed simulation model can quantify seasonal variation in meaningful parameters, such as A and I. Many bio-economic models utilise the static approach to predict financial losses as a result of weeds (Medd 1999), but without considering climatic variation the foundation of these predictions is questionable. The simulation modelling approach described here could significantly improve these predictions, and also be extended to management factors such as sowing date, crop density, and soil type. It may also be possible to relate variation in A and I to seasonal indices (e.g. April–October rainfall, date of the break of the season) in order to develop rules-of-thumb for variation in A and I. Such rules could be incorporated into integrated weed management systems that take better account of inter-seasonal variability.

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