EVALUATION OF A MECHANISTIC MODEL OF WHEAT AND WEED GROWTH

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ABSTRACT

A mechanistic crop growth model, where daily growth is the product of light use efficiency and intercepted radiation, was tested for its ability to simulate biomass growth in wheat and weeds. Wheat was sown at six densities (including 0), in September 1994 in Canterbury and the naturally occurring weed community was either left intact or removed by herbicide. Weed biomass growth was accurately simulated in the presence and absence of the crop, but late-season wheat growth was underestimated, particularly at low sowing densities. Herbicide treatment reduced early-season crop growth, but a grain yield loss of 6.8% due to weed competition, was prevented. Weed biomass accumulation was reduced with increasing wheat density.

Keywords: *Spergula arvensis*, Sirius, mechanistic model, competition, wheat, weed.

INTRODUCTION

There is increasing demand for agricultural weed management strategies to be sustainable both ecologically, ensuring the maintenance of biodiversity, and economically, ensuring that the costs of weed management do not over-run the financial benefits. These two goals are closely entwined and both may be met by strategies in which the intensity and frequency of weed control are optimised. The development of such a strategy requires (1) prediction of the long-term population trajectory of the weed and how this is influenced by alternative weed control methods (Cousens and Mortimer 1995), and (2) prediction of the economic loss caused by the weed (Auld *et al.* 1987). Simple empirical models relating crop yield loss to relative weed leaf area are adequate models for the experimental system from which they are derived (Bourdôt *et al.* 1997; Kenezevic *et al.* 1995; Kropff *et al.* 1995). However, their parameter values are too unstable among years and environments to enable reliable predictions of crop loss from the weed in other environments (Lotz *et al.* 1996). On the other hand, more complex mechanistic models such as *Sirius* (Jamieson *et al.* 1998), that calculate biomass accumulation from intercepted solar radiation, provide realistic simulations of crop biomass growth and grain yield under a wide range of environmental conditions. Weed growth is governed by the same rules as crop growth, so that weed community biomass and seed yield should be able to be modelled, and predicted, in a similar manner. A model that accounts for weed-crop interactions by simulating competition for light and water, could forecast weed load and consequent yield loss for varying scenarios of seasonal weather and weed management. The availability of daily weather data and a minimal amount of soil information mean that such a model can soon form the basis for on-farm decision support.

In this paper we use a simple mechanistic model to simulate crop and weed community biomass growth using crop and weed leaf area data from a single experiment conducted in Canterbury. We evaluate these simulations by comparison with biomass data from the same experiment. Our purpose is to investigate the likely utility of such an approach before developing a more complex simulation model.

MATERIALS AND METHODS

Experimental

Wheat (*Triticum aestivum*, cv. Otane) was planted on 16 September 1994 into plots 10 m long and 1350 mm (9 rows) wide on the Crop & Food Research experimental farm, Boundary Rd, Lincoln. Treatments consisted of 6 different sowing densities of the wheat (0, 50, 100, 200, 400, 800 plants/m²) in the presence and absence of weeds. These were replicated four times in a randomised complete block design. The herbicides Axall (75 g/litre bromoxynil + 75 g/litre ioxynil + 345 g/litre mecoprop) and Granstar (750 g/kg tribenuron methyl) were applied at 2.5 litres/ha and 15 g/ha respectively in 200 litres of water/ha on 17 October when the crop was at the 2-leaf stage to remove the natural weed community.

Each plot was divided in half and nine 220 mm wide x 450 mm (3 crop rows) wide sample quadrats (0.1 m² in area) were located within each half. These straddled the centre crop row and, alternately, the two rows to the left and right of the centre row, leaving the outer two rows as guards. In one of these quadrats, in each half of each plot (2 per plot), the leaf area of both wheat and weeds was measured non-destructively on 19, 25 and 31 Oct, and 7, 14 and 21 Nov 1994. A colour video recording 10 seconds in length, was made of each of these quadrats using a camera positioned vertically above the ground. The images (96 per sampling occasion) were later analysed using a computer programme that discriminated between crop, weed and soil using red, blue and green colour information, and measured their vertically projected areas, or ground cover (Wang and Bourdôt 1997). From the time of crop canopy closure, the non-destructive sampling was replaced by destructive sampling. This began on 21 Nov for the plots of 800 and 400 wheat plants/m² (which reached canopy closure first), on 24 Nov for the plots of 200 and 100 wheat plants/m² and on 28 Nov for the 50 and 0 wheat plants/m² plots. On each of five occasions from canopy closure to crop maturity, two 0.1 m² quadrat samples were taken from each plot (one in each half). Wheat leaf area and biomass was obtained from a 15 tiller subsample on each occasion. The biomass of the weed community and its total leaf area (including stems) were also measured from these quadrats. A Licor planimeter was used for leaf areas and biomass was determined by weighing oven-dried samples.

The population density of each weed species occurring in the plots was measured by counting the number of individuals in each sample quadrat prior to each destructive sampling for leaf area and biomass, and taking the average over time. The grain yield of the wheat was measured from four hand-pulled 0.25m² samples per plot on 31 Jan 1995 for densities of 200 plants/m² and above and on 14 Feb for the 50 and 100 plants/m² densities.

Analytical

Crop and weed biomass and crop grain yield data were analysed by analysis of variance with the appropriate factorial structure for the treatment term.

A mechanistic model of crop growth was used to simulate the seasonal growth in biomass of the wheat and the weed community. In this model crop (or weed) growth rate on each day of the growing season (*GR*) is given as

$$GR = 1.1 \times GC \times SR \quad (1)$$

where *GC* is the plant ground cover (proportion of land covered when viewed vertically from above, *i.e.* the fraction of incident solar radiation intercepted by the crop) and *SR* is daily solar radiation (MJ/m²/day). The constant represents the light use efficiency in units of g/MJ (Jamieson *et al.* 1998), and is conservative among C3 species (Monteith 1997). Accumulated crop (or weed) dry matter is given by the sum of the daily values of *GR*. The daily values of *GC* needed to simulate crop and weed growth for the period up until crop canopy closure were estimated from the video image data by linear interpolation between sample occasions. From the time of canopy closure until the end of crop growth, crop and weed *GC* were estimated from the Beer - de Lambert law as

$$GC = 1 - \exp(-k LAI) \quad (2)$$

where LAI is the crop or weed leaf area measured, expressed as a fraction of the ground area occupied and k is the light extinction coefficient. The value of k required to give realistic simulations of weed biomass growth, as judged by comparing predicted and measured biomass, was determined iteratively. The value of k for wheat simulations was set at 0.45 (Thorne *et al.* 1988).

RESULTS AND DISCUSSION

The weed community on the experimental area consisted of 18 species with a time-averaged total density of 526 plants/m². Six species constituted 83% of the total community density: *Spergula arvensis* (39%), *Veronica persica* (13), *Chenopodium album* (11), *Solanum nigrum* (7.5), *Crepis capillaris* (6.2) and *Viola arvensis* (6.2). The other species in decreasing order of importance were *Capsella bursa pastoris*, *Anagallis arvensis*, *Elytrigia repens*, *Polygonum arviculare*, *Sonchus asper*, *Trifolium repens*, *Sonchus arvensis*, *Senecio vulgaris*, *Stellaria media*, *Rumex obtusifolius*, *Calandrinia compressa* and *Coronopus didymus*.

The simulated and measured values of wheat biomass were in close agreement throughout the growing season at 400 and 800 wheat plants/m², but the simulation underestimated biomass accumulation from mid December at the lower wheat densities as illustrated (Fig. 1). This suggested that the measured LAI provided an underestimate of the total green surface at the lower wheat densities. At these low densities stems may have contributed substantially to light interception, and therefore assimilation and growth, but stem area index was not measured. However, a calculation of half the surface area of a wheat stem of 750 mm height and 5 mm average radius, gives nearly 120 cm² of light-intercepting surface. A population of 200 tillers per m² (4 per plant at the lowest density) would therefore contribute an increase in the green area index (GAI) of 2.4. Although this has a very small effect on the fraction of incident light intercepted in the high-density plots where most light is already intercepted, it has a substantial influence on the calculation of intercepted light at low densities. At the lowest density (50 plants/m²), tillers may have increased GAI from the measured

FIGURE 1: The effect of herbicide at two densities of wheat on wheat biomass accumulation. Means ($n=4$) are shown as; $\blacktriangle$ (800 wheat plants/m², no herbicide), $\bullet$ (50 wheat plants/m², no herbicide), $\triangle$ (800 wheat plants/m², plus herbicide), $\circ$ (50 wheat plants/m², plus herbicide). Simulated biomasses (Equation 1) are given as; unbroken line (no herbicide), broken line (herbicide).

maximum *LAI* of 1.3, intercepting 44% of the light (Equation 2), to 3.7, intercepting 81% of the light. This would nearly double the maximum simulated growth rate at the low density, and simulated biomass accumulation would then have matched measured biomass closely (Fig. 1). In hindsight, a measure of tiller numbers or direct measurements of intercepted solar radiation would have improved the model fit.

The herbicide treatment removed all weeds from the plots but resulted in significant reductions in wheat biomass (averaged over wheat population density) at the 2nd ($P < 0.05$), 3rd ($P < 0.05$) and 4th ($P < 0.10$) sampling occasions (Fig. 1). Such direct effects of herbicide on crop performance will need to be considered in any analysis of weed effects on crop performance.

Weed biomass was significantly reduced at all sampling occasions with increasing wheat population density ($P < 0.001$). Growth in biomass of the weed community was simulated well by the model at all wheat densities, and also in the absence of wheat with $k = 0.1$ (Fig. 2). This value of k is small in comparison with wheat and other grasses (Thorne *et al.* 1988). It occurs because of the morphology of the dominant weed species which either have small tubular leaves (*S. arvensis*) or leaves that stack upon each other (*V. persica* and *C. album*). A result is that *GC* increases only slowly as *LAI* increases, and suggests that the weeds compete among themselves only weakly for light. Additionally, the contrast between wheat and weed values of k means that wheat should compete strongly for light with the weed species. This is confirmed by the fact that weed biomass accumulation was substantially reduced as wheat plant population density increased (Fig. 2). The predicted final weed community biomass was 66, 33, 28, 14 and 9% of that in the absence of the wheat, at wheat densities of 50, 100, 200, 400 and 800 plants/m² respectively.

FIGURE 2: The effect of wheat sowing density on the biomass accumulation of weeds in the absence of herbicide. Means ($n=4$) are shown as; ▲ (0 wheat plants/m²), △ (50 wheat plants/m²), ● (100 wheat plants/m²), and ○ (800 wheat plants/m²). Simulated biomasses (Equation 1) are given as curves.

The grain yield of the wheat increased asymptotically with wheat plant population density, and overall, was significantly higher ($P < 0.05$) in the presence of the herbicide (Fig. 3). Over all densities, the herbicide prevented a loss of 6.8%, calculated as [(yield on 'herbicide' plots - yield on 'no herbicide' plots)/yield on 'herbicide' plots]*100. Hence there was compensation in grain yield for the early reduction in biomass accumulation caused by the herbicide.

FIGURE 3: The effect of herbicide and wheat plant density on grain yield. Means (n=4) are shown as symbols. The LSD(5%) is 0.94 tonnes/ha, and is shown as a vertical line.

CONCLUSION

The results of this study have revealed that biomass accumulation of a weed community may be modelled mechanistically from the amount of radiation it is able to intercept during the growing season. Since wheat crops are also successfully modelled in this manner, competition between a wheat crop and a weed community may be simulated by combining similar models of weed and wheat, and adjusting their respective share of the solar radiation resource according to rules based on the leaf architecture and plant stature. Such research would help us improve our understanding of how weeds and wheat (and other crops) interfere with each others growth and seed yield, and provide the basis for forecasting both crop yield loss, weed biomass, and weed seed recruitment to the soil seed bank.

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