EVALUATION OF A WEED RELATIVE LEAF AREA MODEL FOR PREDICTING YIELD LOSS IN WHEAT

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ABSTRACT

The ability of a simple "two parameter" model based on the relative leaf area of weeds to describe grain yield losses in wheat (*Triticum aestivum* L.) was assessed. Wheat was sown at 100 and 300 plants/m^2 and oversown with six densities of mustard (*Brassica nigra* L.) to generate different levels of "weed" leaf area. Results showed that the model could be simplified to a one parameter model in this particular experiment. The single parameter q, defining the rate at which crop yield declines with increasing relative weed leaf area, did not vary between times of leaf area determination or between wheat sowing densities. However, other workers have shown that q varies substantially between experiments, limiting the predictive value of the model.

Keywords: wheat, mustard, weed, crop yield loss, leaf area model

INTRODUCTION

Intensive use of herbicides in agriculture is unlikely to be a sustainable management practice due to (1) increasing environmental safety concerns, (2) herbicide resistance (Powles and Holtum 1994; Bourdôt 1996) and (3) the economic necessity to reduce agricultural inputs. Herbicide use may be reduced by lowering application rates or by withholding herbicide treatments in crops for which the expected monetary return falls short of the treatment cost. We have recently estimated that 24% of herbicide applications in Canterbury cereal crops are uneconomic (assuming that financial benefits occur only in the current crop) and that this figure varies with spring rainfall (Bourdôt *et al*. 1996). It follows that herbicide use in cereals in Canterbury could be reduced if an economic threshold approach to weed control decision making was implemented.

The economic threshold approach requires that the yield loss resulting from a weed infestation be predicted before the time of herbicide application. Such predictive models must have readily determined input variables. Yield loss from a single flush of weeds is well described by a hyperbolic relationship with weed density in conjunction with an additional parameter to take account of different periods between crop and weed emergence (Cousens *et al*. 1987); unfortunately, the sequence of weed counts required for this model would make it a costly predictive tool. Kropff *et al*. (1995) describe alternative one- and two-parameter models that describe crop loss from observations of the relative leaf area of weeds (the weed's contribution to the total leaf area of weed and crop); these models automatically take account of different times of weed emergence.

The current paper explores the effect of crop sowing density and time of leaf area determination on the parameters of such leaf area models in a wheat crop in Canterbury.

METHODS

Experimental

A field experiment was carried out on the Crop and Food Research Farm at Lincoln in the 1995/96 season. Design was a split plot with four replicate blocks and two treatment factors: crop density (main plots) and weed density (sub plots). On 17 October 1995, wheat (*Triticum aestivum* L.) cv Otane, was sown using an Oyjord drill in rows 150 mm apart and 50 mm deep to achieve populations of either 100 or 300 plants/m^2. On the same day seeds of mustard (*Brassica nigra* L.), used as a model weed, were broadcast to achieve populations of 0, 26, 64, 160, 400 and 1000 plants/m^2. The subplots

were 9 rows wide and 16 m long. The experiment was spray irrigated (20 mm water) on 17/11/95, 7/12/95, 21/12/95 and 3/1/96. To selectively kill the natural weed population, 140 g dicamba / ha (as Banvel 200, 200 g/litre) was applied to all plots through 8002 Teejet nozzles in 200 litres water/ha on 14/11/95 and 28/11/95. To control fungal diseases, 125 g triadimenol / ha (Cereous; 250 g/litre) was applied on 14/11/95 and 15/12/95.

Total aerial dry matters of wheat and mustard were measured on 16/11/95 and 24/11/95 (4 and 5 weeks respectively after crop emergence) from two randomly located 0.1 m^2 samples per subplot. Leaf areas of wheat and mustard were measured using a planimeter on both samples for one randomly chosen replicate on each occasion (this happened to be replicate 1 and 1 respectively). Grain yield was measured on 23/2/96 from 6 x 0.25 m^2 (1.5 m^2) per subplot and adjusted to 14 % moisture content.

Models

The model used here for analysing the response of crop yield to weed competition is the "two parameter" version of the "relative leaf area model" (Kropff *et al*. 1995) as reformulated by Lotz *et al*. (1996) by adding a third parameter (Y_0);

$$Y = Y_0 \left(1 - \frac{qL_w}{1 + (q/m - 1)L_w} \right) + \varepsilon$$

where Y is crop yield and L_W is the weed leaf area index (LAI; leaf area per unit of soil surface) divided by the total LAI of crop plus weed. The parameters are Y_0, representing the weed-free crop yield, q, a measure of the competitiveness of the weed relative to the crop, and m, the maximum yield loss as a fraction of Y_0 (allowing this fraction to be <1). Note that the "one parameter" version of this model has $m = 1$.

The model was fitted for each time of LAI determination separately. The two wheat densities were modelled by including two Y_0, q and m parameters in the model, one for each density.

Since leaf areas were determined for only replicate one, three methods of analysis were tried. Method 1 modelled just the 12 grain yields from replicate one. Methods 2 and 3 modelled the grain yields from all 48 plots using estimates of leaf area for replicates 2, 3 and 4. In Method 2, leaf area (A) for each plot in replicate 2, 3 or 4 was estimated by multiplying the plot's sample weight (W) by the A/W ratio from the corresponding plot in replicate one. The estimated leaf areas for wheat and mustard were then used to estimate L_W for the plot. Method 3 was to derive an average A/W value for each wheat density by meaning the six $\log_{10}(A/W)$ values and antilogging, using this average A/W as described for Method 2. In the case of the last two methods, experimental block differences were also modelled by including three block contrasts.

With each method, models were fitted using the non-linear curve fitting procedure in the statistical package Genstat (Genstat 5 Committee 1993), and the most economical model chosen using F-values to judge the significance of differences between models.

RESULTS

In general, the experimental wheat and the mustard established and grew well, with the mustard being visually very competitive in the first few weeks of growth. Unfortunately, the second dicamba application, applied during the sixth week, defoliated the mustard and most probably reduced its competitive effect from that time on.

Table 1 summarises the sequence of models fitted to the data generated by Method 3 for the first time of LAI determination. Line (2) tells us that the simplification $Y_{01} = Y_{02}$ is unacceptable, i.e., weed-free yields differ between wheat densities, whilst lines (3) to (6) tell us that common q and m values are acceptable. Line (7) tells us that the common m value can be set equal to 1, while line (8) tells us that the common q value cannot be set equal to 1. That is, the simplest adequate model is model (7). Figure 1(a) displays this fitted model along with the data, and gives the fitted parameter values; it also shows that the model fits the data reasonably well.

For the second time of LAI determination, the corresponding F-values (using

Method 3) are very close to those given in Table 1, and the simplest adequate model is again model (7). The model fit is displayed in Figure 1(b).

   The other two methods of analysis also both led to model (7) for both times of LAI determination. Method 2 resulted in F-values and parameter estimates very similar to those given in Table 1 and Figure 1. Method 1, using data from just 12 plots, yielded lower F-values than the other two methods (5% and 1% significant instead of 1% and 0.1% significant for comparisons 1-2 and 7-8 respectively, for both times of LAI determination), although the q values were similar to those for Method 3. However, Method 1 yielded less reliable weed-free yield estimates, based on the atypical grain yields obtained in replicate one, of $Y_{01} = 2.1$, 2.1 and $Y_{02} = 4.8$, 4.9 for the two times of LAI determination, so was not chosen for presentation for that reason.

TABLE 1: **Residual sums of squares (RSS) for models fitted, with various restrictions, to the wheat grain yield data for the first time of LAI determination using method three to estimate weed and crop leaf areas on all plots. The F-values for comparison of models are given. The full model included six parameters, separate Y_0, q and m parameters for each of the two wheat densities (denoted by subscripts 1 and 2). The full model had a model sum of squares of 476.8. For all F tests the residual mean square for the full model (0.5964; 39 d.f.) was used as the denominator; ns = not significant; ** = P<0.01; *** = P<0.001.**

Model restrictions	RSS	d.f.	Models compared	F-value	Sign.
(1) *Full model*	23.26	39			
(2) $Y_{01} = Y_{02}$	30.45	40	1-2	12.06	**
(3) $q_1 = q_2$	23.30	40	1-3	0.07	ns
(4) $m_1 = m_2$	23.29	40	1-4	0.05	ns
(5) $m_1 = m_2 = 1$	23.30	41	4-5	0.02	ns
(6) $q_1 = q_2$, $m_1 = m_2$	23.58	41	4-6	0.49	ns
(7) $q_1 = q_2$, $m_1 = m_2 = 1$	23.64	42	6-7	0.10	ns
(8) $q_1 = q_2 = 1$, $m_1 = m_2 = 1$	53.67	43	7-8	50.35	***
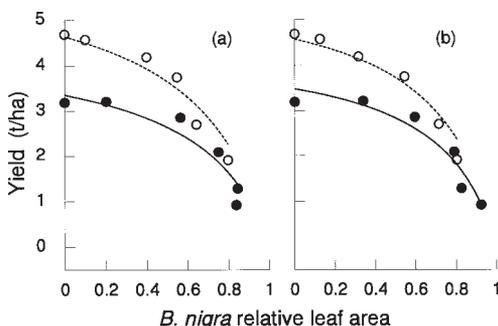
FIGURE 1: **The relationship between wheat grain yield and mustard relative leaf area(L_w) for LAI determinations made (a) 4 and (b) 5 weeks after crop emergence. Solid and broken lines give fitted models, and mean data values are coded ● and O, for wheat sowing densities of 100 and 300 plants/m² respectively. Parameter values are (a)$Y_{01} = 3.36$, $Y_{02} = 4.64$, $q = 0.27$ and $m = 1.0$ and (b) $Y_{01} = 3.48$, $Y_{02} = 4.58$, $q = 0.23$ and $m = 1.0$.**

This study involves an artificial crop-weed system with the weed spectrum restricted to just one weed, *B. nigra,* which is not normally a weed in cereal crops. The primary study objective was to test the weed leaf area model, not to gather data on particular crop-weed combinations. In the event, however, a further artificiality was added when the second dicamba application unexpectedly defoliated the *B. nigra*. This means that the system modelled in this study is one in which the weed competes normally with the crop during the first 5 to 6 weeks after crop emergence, then succumbs to a herbicide application.

The one-parameter leaf area model provided a good description of the decline in wheat yield with increasing relative leaf area of *B. nigra* (Fig. 1), which is in agreement with the results of other studies (Lotz *et al.* 1996; Knezevic *et al.* 1995). However, this does not necessarily mean that the model can reliably forecast crop yield loss from an early LAI determination. In order for the model to do so, the parameter value q needs to be stable for a particular weed/crop association across the variety of conditions under which the crop may be grown in different years and geographical regions. While the current study shows that q is stable across different wheat densities and between the two times of LAI determination within this one experiment, other studies indicate that q declines with time of LAI determination and varies between years and geographical location for a given weed/crop association (Lotz *et al.* 1996; Knezevic *et al.* 1995). A probable explanation is that spatially and temporally variable abiotic factors such as soil fertility and moisture alter the competitive ability of the weed relative to the crop after the time of LAI determination. Also, differences between wheat varieties in their ability to compete with weeds (Lemerle *et al.* 1996) imply that crop cultivar is likely to affect q in these models. Lotz *et al.* (1996) concluded that relative leaf area models cannot be used to predict crop yield loss due to weeds until (1) there is a better understanding of how the parameter values depend upon abiotic factors, so that their values may be adjusted for different conditions, and until (2) a restricted time window for LAI determination is defined that might reduce variation in the parameters and increase the accuracy of prediction.

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