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NOTE

Modelling competition between large crabgrass and glyphosate-resistant soybean in the Rolling Pampas of Argentina

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ABSTRACT

Large crabgrass is considered among the ten most important weeds in Argentina, especially in no-tillage fields, and is one of the most troublesome weeds in soybean. A field experiment was conducted in the Rolling Pampas, Argentina area under a no-tillage system to establish the competition relationship between large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and glyphosate-resistant soybean (*Glycine max* (L.) Merr.). Hyperbolic and exponential models were compared to model the effect of large crabgrass density and biomass on soybean yield. The hyperbolic model represented these relationships better than the exponential model. Weed-biomass models showed a better prediction than weed-density models. Results showed that approximately 50% of soybean yield loss was reached with 4±1 plants m^{-2} or with 256.20±34.45 g dry matter m^{-2} of *Digitaria sanguinalis*.

Key Words: *large crabgrass; soybean; weed density; weed biomass; competition model; hyperbolic model; exponential model*.

INTRODUCTION

Large crabgrass (*Digitaria sanguinalis* (L.) Scop.), an annual weed, is distributed throughout the world's tropical and temperate regions (Simpson, 1990; Marzzoca, 1994; King and Oliver, 1994). It is a prolific seed producer that emerges in spring, flowers and fructifies in summer until autumn, and is propagated mainly by seed (Marzzoca, 1994; King and Oliver, 1994).

D. sanguinalis is a serious problem in many row crops (Mohler and Callaway, 1995; Bhowmik et al., 1999; Sarker et al., 2002; Monks and Schultheis, 1998; Aguyoh and Masiunas, 2003; Fu and Ashley, 2006) and in turf grasses (Walker et al., 1998; Richmond et al., 2003). In Argentina, it is considered to be one of the 10 most important weeds (Mitidieri, 1989), especially for the main Rolling Pampas crops (Mitidieri, 1989; de la Fuente et al., 1999; Suárez et al., 2001). It has also become an important weed in soybean (*Glycine max* (L.) Merr.) (Marzzoca, 1994).

In the last 10 years, many farmers in the Rolling Pampas area have adapted, among other cropping systems, a no-tillage system (Taboada et al., 1998). The reason for this was to reduce the labour requirements and production costs. In addition, such a system conserves soil moisture and reduces soil erosion (Mark et al., 1995; Qaim and Traxler, 2005). A chemical control, especially the use of glyphosate [N-(phosphonomethyl) glycine], is mainly used to control weeds under non-tillage systems in soybean with the RoundupReady® trait (http://monsanto.mediaroom.com/index.php?s=41). This herbicide provides between 98 and 100% control of *D. sanguinalis* (Culpepper et al., 2001; Van Gessel et al., 2001; Norsworthy, 2004).

In spite of such an effective control, researchers have found that *D. sanguinalis* has maintained or even increased its density in no-tillage systems, especially in maize-soybean rotations (Zanin et al., 1997; Tuesca et al., 2001; Davis et al., 2005; Puricelli and Tuesca, 2005). This weed produces a great number of seeds per plant and has two main cohorts during the season (Oreja and de la Fuente, 2005), facilitating its long-term survival. Moreover, because seeds in this system remain in the top soil layer, there is a high percent of emergence (Benvenuti et al., 2001).

Modelling the weed-crop competition should support cost-effective decisions in weed management. In spite of the importance of *D. sanguinalis*' effect on soybean (Leguizamón, 1976), there are no models to study the influence of this weed on soybean yield. The objective of our study was to model the effect of density and biomass of large crabgrass on transgenic soybean yield.

MATERIALS AND METHODS

Field experiments were carried out during 2003-04 in commercial soybean fields in Salto, province of Buenos Aires in the Rolling Pampas, Argentina. The climate is temperate-humid with an annual average rainfall of 950 mm and an annual average temperature of 17ºC (Hall et al., 1992; Soriano et al., 1992). The soils are Argiudoll, typical of the Argentine rolling pampa, with a pH of 6.2 and organic matter content of 2.6%. The experiment was conducted in two fields sown with transgenic soybean naturally infested with *D. sanguinalis*. Each field was divided into nine plots of 16×16 m and arranged in a completely randomized design with three replications. The plot were sanitized and then infested with six *D. sanguinalis* densities (0, 10, 20, 30, 40 and 50 plants m^{-2}).

The distance between the fields was approximately 100 m. Roundup Ready (RR) soybean of group IV was sown on 8 November in 0.35 m rows at a locally recommended seeding rate of 63 kg ha^{-1}. To control winter annual and perennial weeds, glyphosate [N-(phosphonomethyl) glycine] was applied at a rate of 0.84 kg ha^{-1} during the first week of October.

Crop yield, weed plant density and biomass were determined within each plot at crop maturity on 26 March. Sampling was carried out by hand in all the plots using one quadrat of 20 cm by 20 cm per plot for weed plants and three quadrats of 1m by 1m per plot for soybean plants. *D. sanguinalis* and soybean plants were removed from the soil, and stored in bags for further processing. Drying the plants at 70ºC until a constant weight was reached assessed weed and crop biomass. Number of plants, aboveground biomass and yield were expressed per m^{-2}.

To assess crop yield as affected by weed competition, regression models between crop yield and weed density or biomass are commonly used (Cousens, 1985). In the present study, two nonlinear models were compared: a) the hyperbolic model and b) the exponential model. The hyperbolic model is traditionally used in weed science and was proposed by Cousens (1985):

$$y = Y_{wf}\,(1-jd)/(1+kd), \tag{1}$$

where y is crop yield, Y_{wf} is weed-free yield, d is weed density in plants m^{-2} or biomass m^{-2}, and j and k are parameters of the model.

The exponential model is expressed by:

$$y = Y_{wf}\exp(-bd), \tag{2}$$

where y, Y_{wf}, and d are defined as stated above, and b is a parameter of the model.

Both models have been used to represent competition between crops and weeds (Cousens, 1985; Lindquist et al., 1996; Kim et al., 2002; Aguyoh and Masiunas, 2003; Izquierdo et al., 2003; Scursoni and Satorre, 2005). Akaike Information Criterion (AIC) was used to choose the best model (Burnham and Anderson, 2002). It is calculated as:

$$\mathrm{AIC} = -2(\text{log-likelihood})+2k, \tag{3}$$

where k is the number of parameters estimated in the model. For two models, the one having the lower AIC value is considered "better."

For small sample sizes (Burnham and Anderson, 2002), the corrected Akaike Information Criterion ($\mathrm{AIC_c}$) should be used:

$$\mathrm{AIC_c} = \mathrm{AIC}+(2k(k+1))/(n-k-1), \tag{4}$$

where n is the sample size. Although the best model is that with the lowest AIC value, it can be very useful to rank the models' subject to the values of $\mathrm{AIC_c}$. It may show whether there are other plausible model(s) among the group of models studied. The models can be ranked using Δ_i, which is calculated as:

$$\Delta_i = \mathrm{AIC_c}-\min\mathrm{AIC_c}. \tag{5}$$

Δ_i can easily be interpreted using the following rule of thumb (Burnham and Anderson, 2002): $\Delta_i \leq 2$ indicates a strongly plausible model; Δ_i values between 3 and 7 indicate a plausible model; and $\Delta_i > 10$ indicates a very unlikely model.

Akaike weights (w_i) provide another measure of the strength of evidence for each model:

$$w_i = \exp(-\Delta_i/2)\Big/\sum_{i=1}^{n}\exp(-\Delta_i/2) \tag{6}$$

The Akaike weights show the probability that a model is the best among the whole set (n) of candidate models.

Equations 1 and 2 were fitted by the least-squares method assuming a normal error distribution using the non-linear module of GraphPad Prism v.4 (Motulsky and Christopoulos, 2005). Adequacy of the model fit was examined using residual analysis and pseudo R^2.

RESULTS

The models examined in this paper provided an adequate description of competition between soybean and *D. sanguinalis* (Table 2). Parameter estimates are shown in Table 1. According to the AIC-based model selection, of the two response models evaluated the hyperbolic model presented a better AIC value than the exponential model for weed density (Table 2a). However, the exponential model was plausible as Δ_i was smaller than 2 (Table 2a) (Burnham and Anderson, 2002). The hyperbolic model had a 60% probability to be the best model to represent the relationship between soybean and *D. sanguinalis* density (Table 2a).

For weed biomass, AIC results showed that the hyperbolic model was the better model of the two response models evaluated (Table 2b). In this case, the exponential model was very unlikely ($\Delta_i > 10$; Table 2b). The Akaike weight for the hyperbolic model indicated that this model had 100%- probability to be the best model to fit weed biomass (Table 2b). These results confirm those obtained by Cousens (1985), who claimed the hyperbolic to be a general model for crop-weed competition.

Weed biomass had higher values of R^2 than weed density (Table 2), indicating it to be a better predictor of soybean yield. Similar results were obtained by Juan et al. (2003) for Euphorbia dentata in soybean fields.

Simulating soybean yield loss according to the fitted hyperbolic equations showed that over 50% of yield losses were reached with 4±1 plants m^{-2} or with 256.20±34.45 g dry matter m^{-2}. This study quantified the great competitive ability of *D. sanguinalis* with soybean. Even emergence of 2 plants m^{-2} of large crabgrass should be controlled to avoid significant yield loss (two weed plants cause around 25% yield loss). The average yields for soybean crops in the Rolling Pampas are around 2700 kg ha^{-1}. A 25% yield loss equates to 675 kg of soybean. Under this situation, always is justified the use of herbicide control of *D. sanguinalis*, otherwise the economic losses should be unsustainable for Argentinean farmers

Results of this study have important implications in weed integrated pest management programs for soybean. They could serve as the basis for making decisions on the use of weed management strategies as well as for developing bioeconomical models and weed thresholds for Argentinean farmers. However, variation in parameter estimates could limit the use of these equations in weed management. One way to improve the predictability of these equations would be to incorporate factors (e.g., crop density, temperature) affecting the relation between yield loss and weed interference in the form of covariates and conduct the experiment in more crops and locations.

Table 1. Parameter estimates for the models tested to describe the relationship between a) soybean yield-*D. sanguinalis* density and b) soybean yield-*D. sanguinalis* biomass. The numbers in parenthesis are standard errors.

Models	Parameters			
	Y_{wf}	*j*	*k*	*b*
a)				
Hyperbolic	3262 (459.5)	-0.04 (0.08)	0.24 (0.22)	-
Exponential	2910 (412.8)	-	-	0.06 (0.02)
b)				
Hyperbolic	3157 (391.3)	9×10^{-4} (7×10^{-4})	2×10^{-3} (2×10^{-3})	-
Exponential	3124 (325.0)	-	-	2×10^{-3} (6×10^{-4})

Table 2. Values of Akaike´s information criterion (AICc). a) *Digitaria sanguinalis* density. b) *D. sanguinalis* biomass.

Equation	a)	AIC_c	Δ_i	w_i	R^2	b)	AIC_c	Δ_i	w_i	R^2
Exponential		243.31	0.82	0.40	0.48		274.2	34.4	0.00	0.66
Hyperbolic		242.49	0.00	0.60	0.57		239.8	0.00	1.00	0.66

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