The Development and Validation of a Simple Yield Loss Prediction Model for Soybean Rust

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INTRODUCTION

Soybean rust (SBR) is a serious threat to soybean production and has the potential to reduce crop yields by as much as 80%, if it arrives early in the crop's development. Disease control measures are economically viable when yield loss is sufficient to justify the cost of the control measures. Models that predict expected yield loss can serve as useful management decision aide tools.

In a two year study conducted in Brazil, SBR-induced yield loss was found to be due to: (i) accelerated leaf drop, (ii) reduced green leaf area (GLA) and (iii) reduced photosynthetic capacity of GLA. The reduced photosynthetic capacity of GLA has been quantified in controlled environment and field experiments (Kumudini, et al., 2008a & b). Our understanding of these factors was used to develop the model.

OBJECTIVES

The objectives were to:

1) develop a simple yield loss prediction model for soybean rust, based on the mechanism by which the disease reduces yield.

2) validate this model with independent data sets.

METHODOLOGY (Pt 1)

Model Development (Brazil): The Effective Leaf Area Index (ELAI) is a calculated value of the leaf area that is effective in contributing to photosynthesis and thereby yield (Jesus Junior et al., 2003). The calculation of ELAI takes all three factors that affect SBR-induced yield loss into consideration.

The ELAI is calculated as follows: $ELAI = LAI(1-x)^{\beta}$, where x is the proportion of diseased tissue and β is the Bastiaans coefficient. The disease severity from the trial (Fig. 1) was used to calculate the ELAI for the control and SBR treatments, using a Bastiaans coefficient of 3 (Fig. 2).

The impact of the disease on ELAI must incorporate the temporal aspect of SBR damage. This is achieved by integrating ELAI over time (R5 to R7) to get Effective Leaf Area Duration (ELAD).

$$ELAD = \sum_{1}^{n=i} [(ELAI_i + ELAI_{i+1})/2] \times (t_{i+1} - t_i)$$

where n is the number of assessments, $ELAI_i$ is the ELAI at time = t_i, and $(t_{i+1} - t_i)$ is the interval (days) between two consecutive assessments.

ELAD as % of control was plotted against yield as % of control (Table 1 and Figure 3). The linear relationship ($R^2 = 0.82$) is the basis of the model (Eq. 1).

RESULTS: Model Development (Brazil)

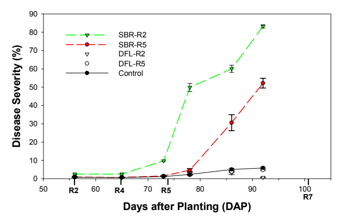

Figure 1. Disease severity vs. days after planting (DAP) for soybeans infected with soybean rust at the R2 and R5 growth stages (SBR-R2 and SBR-R5), manual defoliation treatments mimicking leaf loss due to SBR starting at R2 and R5 plots (DFL-R2 and DFL-R5), and a control treatment during 2006–2007 growing season. Vertical bars represent ± standard error of the mean.

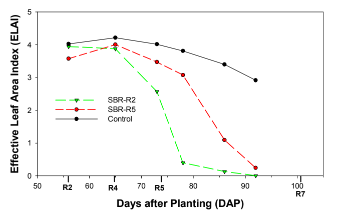

Figure 2. Effective Leaf Area Index (ELAI) plotted over time for control and SBR treatments from 2006/2007 Brazil trial. A Bastiaans coefficient of 3 was used to calculate the ELAI for the 2007 Brazil trial.

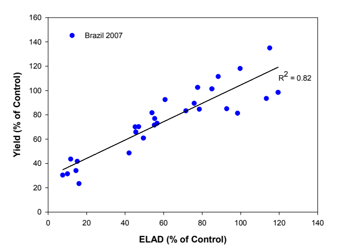

Figure 3. Relationship between effective leaf area duration (integrated from R5 to R7) and yield (% of control) Y = 0.75 ELAD + 29. Data from Londrina, Brazil in the 2006/2007 growing season.

Row Width	Cultivar	Trt	Yield (bu/ac)	% SBR at R6/R7	Yield (% of Control)
18"	MG7 (Dt)	Control	47.2	5.9	
	BRS 154	SBR-R2	16.1	83.2	34.1
		DFL-R2	42.0	0.7	89.0
		SBR-R5	30.8	52.2	65.3
		DFL-R5	46.3	4.8	98.1

Table 1. Summary of yields and SBR severities from 2006/2007 Londrina, Brazil trial.

Yield Loss Equation:

Yield (% of Control) = 0.75 x ELAD (% of Control) + 29% :Eq. 1

METHODOLOGY (Pt 2)

Model Validation (Florida): Field trials were planted on July 10 and 11, 2007, at the University of Florida, Quincy. Treatments included two row widths (Fig. 4), determinate (Dt) versus indeterminate (Idt) genotypes, and SBR starting at two different times as well as a disease-free control (Folicur (4 fl. oz/a) used to limit disease progress). Phenology, leaf area, disease severity and yield were measured. Leaf area was measured non-destructively using a LAI-2000 (LiCor Environmental Sciences, Lincoln, NB). SBR arrived late (R6) and developed slowly during the season resulting in low disease severities at R7 and small yield reductions (Table 2). ELAI was calculated and plotted for the treatment combinations (Fig. 5). ELAD (R5 to R7) was calculated as explained earlier.

Model Validation (Georgia): On June 10, 2008 validation trials were planted at University of Georgia, in Tifton, GA. Treatments included two maturity group genotypes (MG7 and MG8), and SBR starting at two different times as well as a disease-free control (Folicur (4 fl. oz/a)). Phenology, leaf area, disease severity and yield were measured. Leaf area was measured non-destructively using a LAI-2000 on a weekly basis. Disease development was first observed at the R6 and R5 growth stages in MG7 and MG8 cultivars, respectively. Disease severity was assessed weekly. After R7, the plots were harvested for biomass, harvest index, and seed yield.

SBR severity was greater at R7 for the MG 8 than the MG 7 cultivar as the epidemic had more time to progress (Table 3). The yield losses were not very large, but accelerated leaf drop was evident in the plots (Fig. 6). ELAI was calculated and plotted for the treatment combinations (Fig. 7). ELAD (% of control) was plotted against yield (% of control) for the two cultivars (Fig. 8). There was no relationship between the two parameters for the MG7 cultivar ($R^2 = 0.001$).

Observed vs. Predicted: The Yield Loss Equation was used to calculate the predicted % Yield values from the % ELAD data for each of the trials. The observed yield values were plotted against the predicted values (Fig. 9). Parameters (R^2 and root mean square error) assessing how well the independent and validation data fit the Yield Loss Equation were calculated for the trials (Table 4).

RESULTS: Model Validation (Florida)

Figure 4. Plots in early September in Quincy FL with 15" and 30" row widths.

Row Width	Cultivar	Disease	Yield (bu/ac)	% SBR at R7	Yield (% of Control)
15"	Dt (MG5)	Control	39.6	0.0	
	DP5414RR	Early	35.6	6.3	89.8
		Later	34.7	0.0	87.6
	Idt (MG5)	Control	42.5	0.0	
	DP5335RR/S	Early	39.5	6.5	93.0
		Later	38.4	0.0	90.3
30"	Dt (MG5)	Control	43.2	0.0	
	DP5414RR	Early	40.7	6.8	94.1
		Later	41.5	0.3	96.1
	Idt (MG5)	Control	44.4	0.0	
	DP5335RR/S	Early	35.3	6.8	79.5
		Later	37.6	0.0	84.5

Table 2. Summary of yields and SBR severities from Quincy, Florida in 2007.

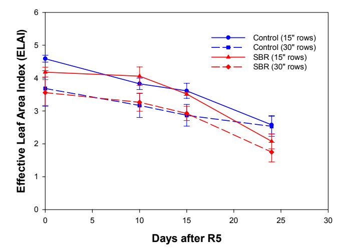

Figure 5. Effective Leaf Area Index (ELAI) plotted over time for control and early SBR treatments for the Dt cultivar at 15" and 30" row widths from 2007 Florida trial.

RESULTS: Model Validation (Georgia)

Row Width	Cultivar	Trt	Yield (bu/ac)	% SBR at R7	Yield (% of Control)
36"	MG7 (Dt)	Control	58.4	0.3	
	AGS 758 RR	Early	52.9	8.6	90.6
		Later	54.2	0.6	92.9
	MG8 (Dt)	Control	70.2	1.6	
	Prichard RR	Early	65.2	33.6	92.9
		Later	67.6	0.6	96.3

Table 3. Summary of yields and SBR severities from Tifton, Georgia in 2008.

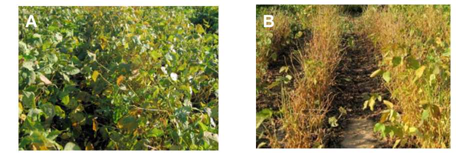

Figure 6. Control (A) and Early SBR plots (B) in mid-October at Tifton GA. Note the accelerated leaf drop.

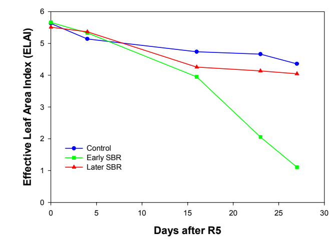

Figure 7. Effective Leaf Area Index (ELAI) plotted over time for control, early and later SBR treatments for the MG8 cultivar from 2008 Georgia trial.

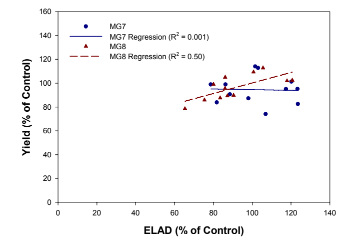

Figure 8. Relationships between effective leaf area duration (integrated from R5 to R7) and yield (% of control) for MG7 ($R^2 = 0.001$) and MG8 ($R^2 = 0.50$) plots in Georgia 2008 trial.

RESULTS: Observed vs. Predicted

Trial	n	R^2	rmse
Brazil 2006	30	0.71	17.0
U.S. & Brazil 2006	90	0.61	14.4

Table 4. Summary of parameters (R^2 and root mean square error) assessing how well the independent and validation data fit the Yield Loss Equation.

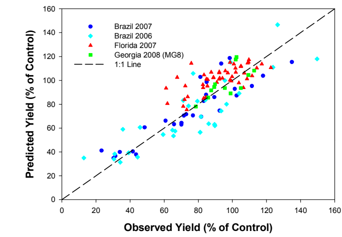

Figure 9. Observed vs. predicted yields for the trials.

DISCUSSION

The independent data set from Brazil (2006) affirmed the fit of the yield loss equation (Table 4).

In Georgia, the disease arrived later in development (R6) and resulted in a lower disease severity (8.6%) for the MG 7 cultivar. The LAI at R5 of the MG 7 cultivar was well above that required for 95% light interception (Board, et al. 1997). In addition there was a great deal of variability in the MG 7 data from this location (Fig. 8), and so it was decided that the MG 7 data would be omitted from the analysis.

Because in both U.S. locations SBR arrived late in the growing season (R5 or R6) and resulted in mostly low disease severity, the range of the model that could be tested was low (only up to 20% yield loss). Considering that there was a limited range in values to get a good fit, with individual and combined U.S. data sets, the Brazil 2006 independent data set was included with the U.S. data set. Using the larger range of values obtained by combining the U.S. data with Brazil 2006 data allowed a better test of the fit of our model and it affirmed the yield loss prediction model ($R^2 = 0.61$) (Table 4).

SUMMARY

Data from Brazil was used to develop a simple yield loss prediction model using the relationship between proportional decreases in ELAD and proportional decreases in yield. Validation data from the U.S. fit this relationship well if the control LAI ≥4 and there were moderate decreases in ELAI and ELAD from SBR. The independent data sets affirm the ELAD/yield relationship across a number of regions and production practices. These data support our efforts to use our understanding of the mechanism of SBR yield loss to develop a reliable yield loss prediction tool.

LITERATURE CITED:

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