Can we simulate the impact of soybean rust in the southern soybean production regions of the United States?

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SBR YIELD LOSS MODEL PROJECT

Introduction

Soybean rust (SBR) caused by *Phakopsora pachyrhizi* H. Sydow and P. Sydow, is a serious threat to soybean production in a number of countries worldwide. In the United States, southern regions are at most risk of developing SBR epidemics late in the growing season. Since SBR develops late in the growing season, it may not always be economically practical to spray fungicides. Fungicide applications are economically viable only when expected yield losses are sufficient to justify the cost of the control measures. Therefore, yield loss models that can predict expected yield losses can serve as useful decision aid tools for managing SBR in the southern United States. However, due to the exotic nature of the pathogen that causes SBR, federal restrictions have prohibited field inoculation that are necessary for the study of the impact of the disease on yield. One alternative is to simulate the impact of the disease on soybean yields under the various management practices common in the southern production region. **In order to successfully simulate the impact of the disease on soybean yield, a three step approach is needed:**

STEP 1) DETERMINE THE MECHANISMS BY WHICH THE DISEASE DAMAGES YIELD FORMATION PROCESSES OF A SOYBEAN CANOPY.

STEP 2) SIMULATE THE DAMAGE CAUSED BY THE DISEASE ON A HEALTHY SOYBEAN CANOPY

STEP 3) VERIFY THAT THE DAMAGE CAUSED BY THE SIMULATION RESULTS IN SIMILAR YIELD LOSSES AS WHEN A DISEASE WAS PRESENT.

Step 1: Determine how SBR reduces yield?

Soybean rust impact the plant's ability to intercept and absorb radiation and limit yield through accelerated leaf drop and reduction in green leaf area (due to necrotic and chlorotic lesions on the remaining leaves) (Fig. 1 A, B, and C) and may also impact the photosynthetic activity of the apparently healthy (green) parts of the leaves [3]. A controlled environment study of the soybean rust pathosystem confirmed the impact of the disease on photosynthesis to go beyond that which is due to reduced radiation absorption alone [4]. This suggests that yield loss due to SBR must take into consideration not only loss in green leaf area for light interception, but also the impact of the disease on the plant's photosynthetic capacity.

Figure 1: A) Health soybean canopy, B) SBR Infected plant canopy shows leaf drop, C) Reduced green leaf area of intact leaflet due to SBR lesions.

Bastiaans introduced the concept of virtual lesions as a means of quantifying the effect of disease on leaf photosynthesis. The term virtual lesion was used to describe the area of the diseased leaf (Fig. 1 C) where photosynthesis is negligible. Bastiaans [2] related the net photosynthetic rate (*Px*) of a diseased leaf to that of a healthy leaf (*Po*) as: $Px = Po\,(1-x)^{\beta}$ where *x* is the proportion of the leaf area covered by visible lesions and β is defined as the ratio between the sizes of the virtual and the visual lesions [2]. The β coefficient calculated can be utilized together with an estimate of leaf drop and reduction in green leaf area to determine the photosynthetically effective leaf area [1].

$$ELAI = LAI(1-x)^{\beta}$$

Where LAI is leaf area index. This effective leaf area represents the photosynthetically effective leaf area. The impact of SBR on yield is cumulative throughout the growing season during seed formation process [1]. Since, the effect of the SBR on ELAI only refers to a single point in time, to truly evaluate the season-long impact of the disease, the ELAI must be integrated over time to get effective leaf area duration (ELAD).

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

Based on field studies in Brazil, a good relationship between yield and ELAD has been shown (Fig. 2).

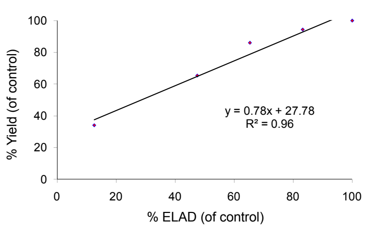

Fig 2: The relationship between ELAD and yield relative to control in a SBR-infected field trial conducted in Brazil in 2007.

Hypothesis

ELAD takes into account the impact of leaf drop, reduction in green leaf area and the impact of the disease on photosynthesis, the primary factors responsible for yield loss due to SBR. Therefore, it may be possible to simulate the impact of the disease on yield by imposing the changes in ELAI through out the growing season that is apparent in a diseased canopy.

Objective

To simulate the SBR injury on a healthy soybean canopy by imposing the changes in ELAI observed in a diseased canopy

Step 2: To simulate SBR damage on a healthy canopy

Methodology

EXPERIMENTAL DESIGN:

The experimental approach was conducted using randomized complete block design with three disease simulation treatments arranged in split-plot with 4 replications. The treatments were to mimic SBR starting at i) control, ii) R2, and iii) R5. The hypothesis tested in two locations: Louisiana State University (LA) in 2008, and University of Kentucky (KY) in two years 2008 and 2009.

TREATMENTS:

1. Control: The LAI of the control is measured through out reproductive plant development. Until plants reach R5, destructive samples ($0.5m^2$) were obtained and leaf area measured using a leaf area meter (LI-3000). Leaf number per square meter was also determined and used to calculate average area per leaf. Because LAI reaches a maximum near R5, LAI during the R5-R7 seed filling period was determined by subtracting the LAI of fallen leaves (collected one day prior defoliation from 1 m^2 wired enclosures) from the R5 LAI. The LAI of fallen leaves was calculated as [(number of fallen leaves) x (area per leaf) / area of $1m^2$]. In the absence of SBR LAI is equal to ELAI.

2. Mimic SBR starting at R2: Mimic the reduction in ELAI due to SBR through manual leaf removal. The defoliation targets (as % of control LAI) were calculated based on the observed changes in ELAI obtained from the Brazilian trial when SBR started at R2 (i.e. over different growth stages) [1] (Fig. 3 A and B). For example, the defoliation target for this treatment at R5 in KY was 47% of control LAI. All manual defoliations were performed by progressively removing leaves from the bottom of the canopy upward to mimic the natural progress of effective leaf loss due to SBR (Fig. 4).

3. Mimic SBR starting at R5: Same procedure was used to calculate and impose the change in ELAI as in treatment 2 except the targets were different. For example, for this treatment the defoliation target at R5 in KY was 15% of control LAI.

MEASUREMENT:

Yield: Seed yield determined at R8 by manually harvesting $4.6m^2$ area.

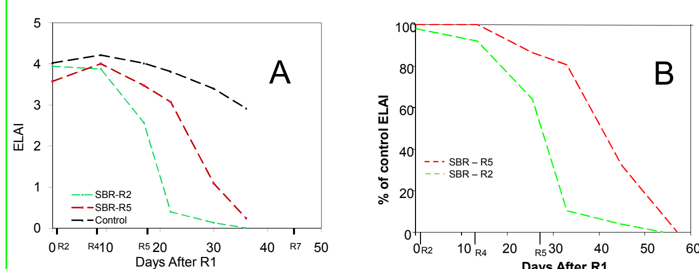

Figure 3: A) Effective Leaf Area Index (ELAI) over time for control and SBR treatments from 2007 Brazil trial. B) Target reduction of effective leaf area index (ELAI) of treatments to mimicking leaf loss when SBR onset at R2 and R5.

Figure 4. Photograph taken under the canopy of a defoliated plot in mid-August at Lexington, KY.

Step: 3 Verify the damage from simulation is similar to damage caused by SBR

Result

Mimicking onset SBR at R2 reduced yield by 68% in both KY and LA, while SBR at R2 reduced yield by 66% in the Brazil trial (Fig. 5). Mimicking onset SBR at R5 reduced yield by 35%, and 42%, in KY and LA; respectively, while SBR at R5 reduced yield by 35% in the Brazil trial (Fig. 5). There is correlation between percent ELAD of control and percent of yield reduction in KY and LA and this correlation was consistence for results obtained from the Brazil trial (Fig. 6). Analyzing goodness of fit test by plotting observed and predicted yield values showed good fit to 1:1 curve ($P < 0.0001$) (Fig. 7).

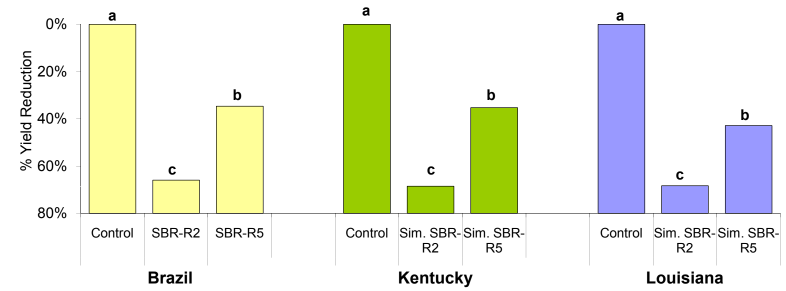

Figure 5: Percent reduction in yield due to SBR infection in field trials in Brazil, and simulated SBR injury by manual leaves defoliation in field trials in LA and KY.

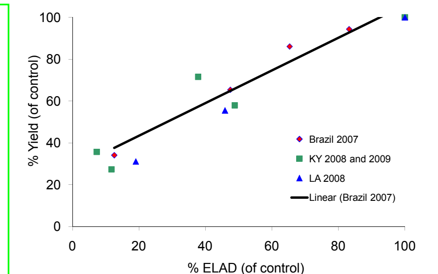

Fig 6: The relation between the percent of ELAD and percent of control yield for soybean under diseased (Brazil) and simulated SBR injury (LA and KY).

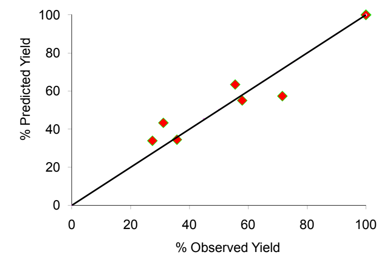

Figure 7: Soybean observed against predicted yield across locations (LA and KY). RMSE = 7.3 and adjusted R^2=0.93. The slope is not significantly different from 1 (*P*= 0.26) and the intercept is not significantly different from zero (*P* = 0.24).

Discussion

In this study healthy soybean canopies were manually defoliated to mimic the impact of SBR on accelerated leaf drop, reduction in green leaf area and the impact of SBR on photosynthesis i.e. the changes in ELAI likely in a SBR infected canopy. This simulation of diseased ELAI on healthy canopies resulted in similar yield losses as in trails where SBR was present (Fig. 5). The relationship between ELAD and yield which was previously confirmed in Brazilian studies where the disease was present, was consistent with the relationship between ELAD and yield found in the SBR simulation trials in southern US (Fig. 6).

To confirm the rigor of simulating diseased injury using ELAD, the model derived from the SBR-infected field trial conducted in Brazil in 2007 (Fig. 2) was used to predict the yield losses of the simulation trails in southern US (Fig. 7). The fact that the model derived from SBR-infected data successfully predicted the yield losses in simulation trials (R^2=0.93, Fig. 7) confirms the effectiveness of the use of ELAD to simulate the damage caused by SBR. The current study confirms that ELAD can be used to simulate the damage caused by SBR to soybean yield.

Conclusion

Manual defoliations mimicking the changes in ELAI observed in diseased canopies is an effective method to simulate the impact of SBR on yield. These finding open an avenue to study the impact of the disease on yield reduction without the need for field inoculation. Using simulation of ELAI under different environmental conditions, season lengths, and cultural practices in two separate years showed the rigor of the relationship between relative ELAD and relative yield reduction.

Field studies conducted in Brazil showed that using the disease severity and area under disease progress curve are not accurate methods to predict yield loss due to SBR [3]. The use of ELAD could prove to be an effective way to develop a yield loss prediction model for SBR.

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