PRECISION TOOLS TO EVALUATE ALTERNATIVE WEED MANAGEMENT SYSTEMS IN SOYBEAN

T.M. Blackmer and P.M. Kyveryga

On-Farm Network
Iowa Soybean Association
Ankeny, Iowa

ABSTRACT

Instances of glyphosate resistance in weeds are increasing in Iowa. Farmers may face significant economic loss from improperly managing glyphosate resistance of some weed species in soybean (*Glycine max* (L.) Merr.) production. The objective of this study was to utilize yield monitoring technology and digital aerial imagery to compare soybean yield and economic performance of the traditional weed management based on two applications of glyphosate (G2) with a program replacing first glyphosate application with a residual herbicide (R+G), Extreme. The comparisons were made in at least three alternating strips in eight field-scale on-farm trials in 2008 and in 20 trials in 2009. Both treatments received a second glyphosate application in 15-50 days after the first herbicide application. Late-season digital aerial imagery was used to evaluate soybean canopy differences and characterize spatial variability in yield differences (YD) calculated between R+G and G2 treatments every 30 to 50 m along the herbicide strips. Hierarchical analysis was used to identify field and within-field level factors that affected the observed YD. On average in each year, R+G treatments produced a slightly reduced soybean yield (by 15 or 20 kg ha^{-1}) than G2 treatments. The additional cost of residual herbicide was about $45-50 ha^{-1} more than that of the two applications of glyphosate. Trials receiving >50 cm of cumulative March through May rainfall in 2008 were about 3 times more likely to have an economic soybean yield loss (>100 kg ha^{-1}) in strips where Extreme herbicide was used than those trials receiving <50 cm of early season rainfall. On-farm studies using precision agriculture technologies should help find alternative weed management systems that rely less on glyphosate and quantify the potential economic loss or benefits from reduced glyphosate applications on soybean.

Keywords: Yield monitoring, digital aerial imagery, weed management, glyphosate resistance, on-farm field-scale studies.

INTRODUCTION

Iowa farmers used glyphosate-resistant (GR) soybean varieties since their commercial introduction in 1996. The latest statistics suggests that 97% of the 2011 soybean acreage in Iowa was planted to GR soybean (USDA-ERS, 2011). The use of GR varieties has benefited soybean production by substantially decreasing the use of other herbicides, saving application timing, simplifying weed management, and by increasing soybean yields (Gianessi, 2008; Owen et al., 2010). Although farmers pay a higher price for soybean seeds with GR technology, the cost of glyphosate has dramatically decreased during the last 5 yrs, making glyphosate based weed management the most economical among other weed management systems.

However, after a decade of relying on the GR technology in both corn and soybean, several common weed species have gradually developed the resistance to glyphosate (Owen, 2008). This resistance is attributed to changing weed population species (i.e., weeds that are better controlled by the herbicide have changed for those that are not well controlled), and some genetic changes of soybean plants. In Iowa for example, GR have been documented in three weed species including Common Waterhemp (*Amaranthus tuberculatus (syn. rudis)*), Giant Ragweed (*Ambrosia trifida*), and Horseweed (*Conyza canadensis* (Weed Science Org, 2011). Although the prevalence of these weed species is very local and not yet considered significant, a rapid proliferation of these weed species across Iowa could potentially have a devastating economic effect on soybean production. Therefore, scientists, industry, and practical agronomists suggest using a proactive management for reducing these potential effects of widespread glyphosate weed resistance and seek alternative options for glyphosate based weed management (Owen, 2008; Shaw et al., 2011).

One of proposed strategy for reducing weed resistance to glyphosate and delay proliferation of these weed species is to use herbicides with different modes of action. This might include the wide use of soil applied pre-emergence or post-emergence residual herbicide or tank mixes with glyphosate. However, farmers are concerned that replacing glyphosate applications with other herbicides will cause yield losses, reduce control of some other weed species, and significantly increase production costs.

Most studies testing alternative systems for glyphosate-based weed management in soybean were done using small-plot experiments or unreplicated half-field sized blocks within farmers' fields (Wilson et al., 2011). The data from on-farm replicated large-scale trials comparing alternative weed management systems to the glyphosate-based system in soybean are limited. Also, none of these studies have addressed the effects of spatial variability on soybean yields when evaluating alternative weed management systems and effects of factors that influence this variability at different scales.

The objective of these on-farm evaluations was to estimate the yield effect from substituting Extreme, a residual herbicide, for the first glyphosate application on soybean. In addition, the study was intended to characterize variability in yield differences (YD) between

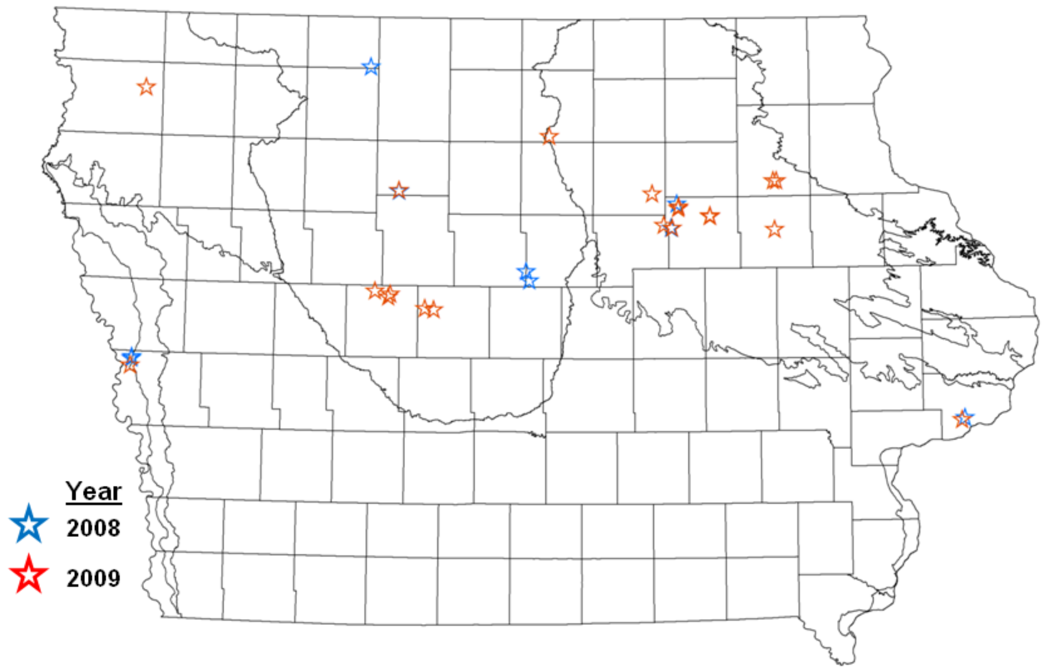

Figure 1. Locations of on-farm evaluation trials comparing a treatment with application of Extreme residual herbicide followed by one application of Glyphosate (R+G) and a treatment with two applications of Glyphosate (G2) on soybean in eight on-farm evaluation trials conducted across Iowa in 2008 and 20 trials in 2009.

the two weed management strategies and identify field and within field-level factors that influence YD.

MATERIALS AND METHODS

The common weed management program on GR soybean in Iowa consists of two post-emergence applications of glyphosate. In this statewide study (Fig. 1), one application of Extreme residual herbicide was followed by one application of glyphosate and was compared with two applications of glyphosate in eight on-farm evaluation trials in 2008 and in 20 on-farm trials in 2009. Extreme controls a wide range of broadleaf weed species and several grasses by combining the burndown weed control of glyphosate and the residual weed control of Pursuit. Each on-farm trial had two alternating treatments such as Extreme with a follow up of glyphosate (R+G) and two applications of glyphosate (G2). The treatments were replicated 3 to 5 times and were applied in a systematic order to avoid application errors and help facilitate the estimation of yield differences between the two treatments in a common way in each trial (Fig. 2).

In the majority of the trials, Extreme was applied before soybean plants had already emerged in 2008 and after soybean plants emerged in 2009. The timing of herbicide applications varied depending on the year of the study, planting time, soybean emergence, and weed pressure.

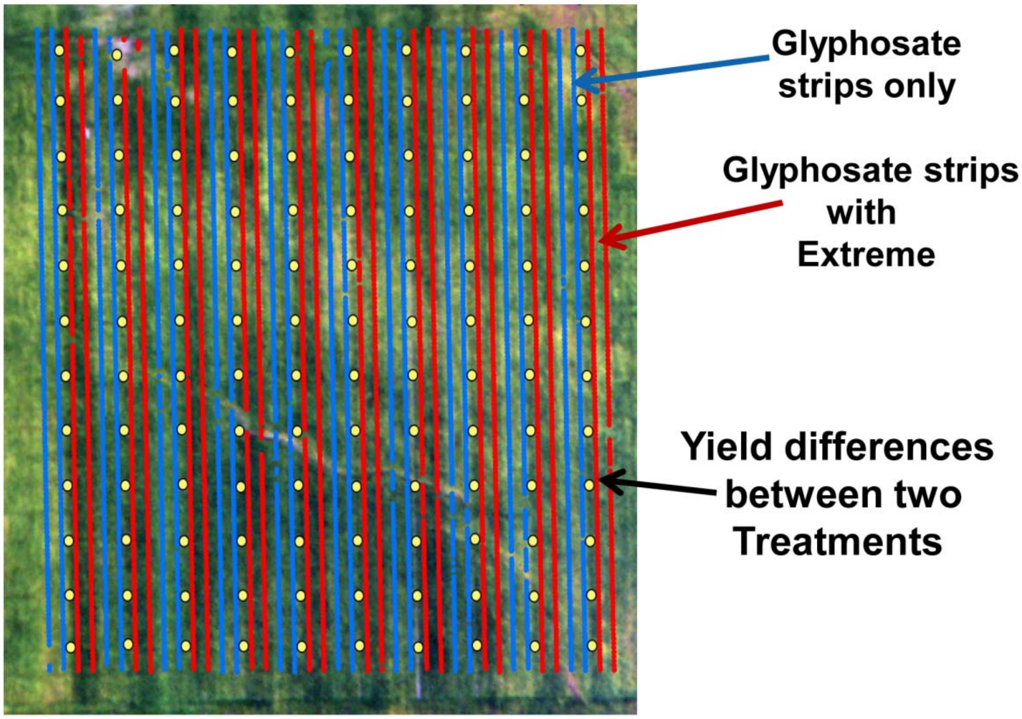

Figure 2. Locations of herbicide treatments and yield differences calculated between a treatment with Extreme residual herbicide followed by one application of glyphosate (R+G) and a treatment of two applications of glyphosate (G2) on soybean. Notice visible differences between the treatments in the soybean canopy reflectance on the digital color aerial imagery taken in late August of 2009.

All herbicide applications were done later in 2008 than in 2009 due to delayed planting and above normal spring rainfall (Fig. 3). In both years , most of the follow-up glyphosate applications in R+G treatment were done at the same time as the second glyphosate applications in G2 treatment. In 2009, Extreme application timing coincided with the first glyphosate application in the G2 treatment.

Data Processing and Statistical Analysis

Visual analysis of color (blue, green and red bands) digital aerial imagery was done to identify reflectance differences in the corn canopy between R+G and G2 herbicide treatments. Herbicide strips were harvested with grain combines equipped with yield monitors that recorded yield observations every 1 sec. The yield data were cleaned by deleting observations that were located < 50 m from the beginning and end of the strips, and from flooded areas, waterways, and buffer strips. Individual yield observations were aggregated into 30-50 m long grid cells along each pair of the treatments. Yield differences (YD) were calculated as differences in aggregated yields between R+G and G2 treatments. Each trial had from 50 to 300 individual YD

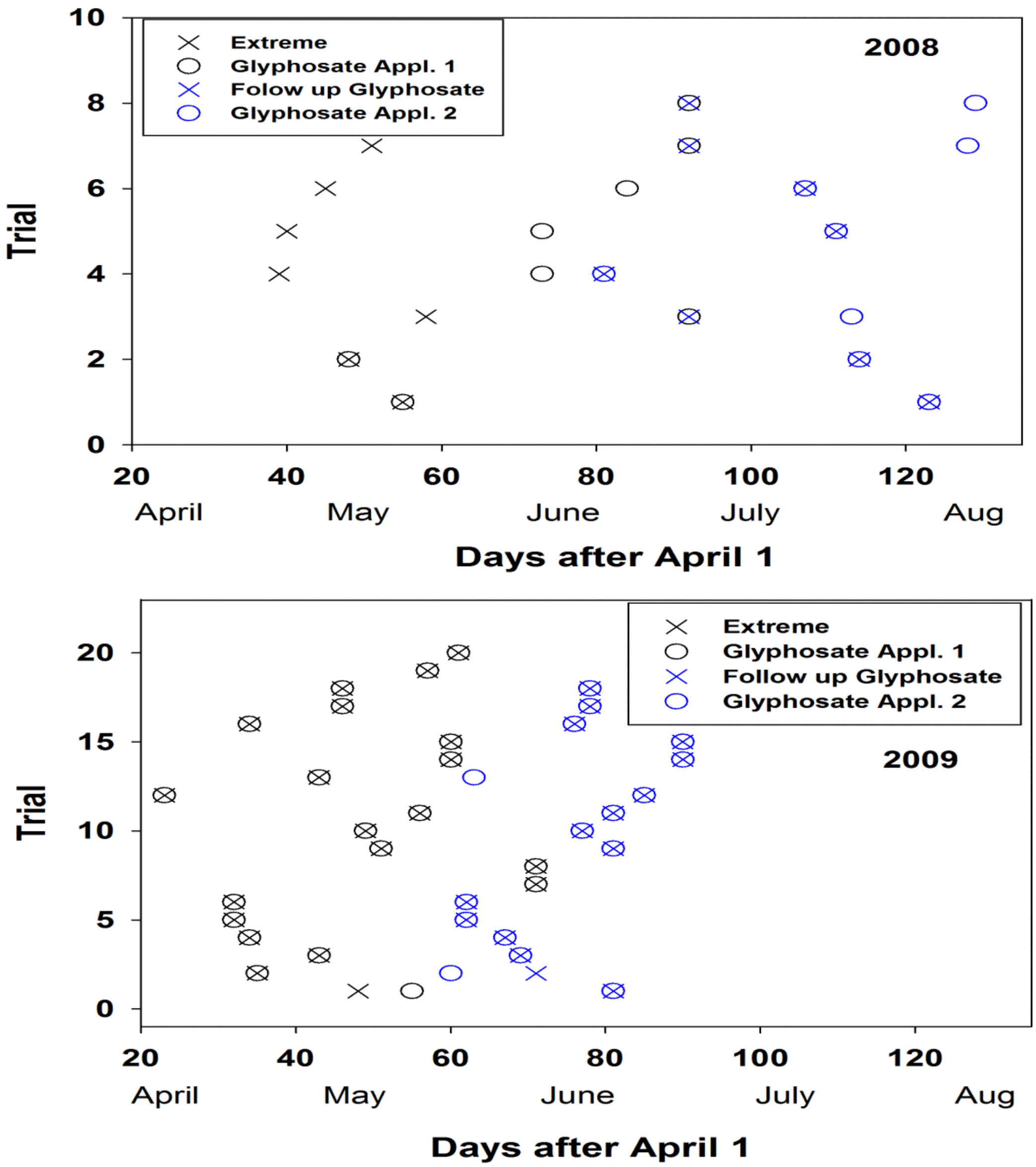

Figure 3. Application timing of weed control treatments with Extreme residual herbicide followed by one application of glyphosate (R+G) and two applications of glyphosate (G2) on soybean in eight on-farm evaluation trials conducted across Iowa in 2008 and 20 trials in 2009.

observations (Fig. 2). Yield difference observations that were two standard deviations above or below the mean YD for a trial were also eliminated.

Monthly rainfall estimates for each trial were obtained from the Iowa Environmental Mesonet (Iowa Environmental Mesonet). Soil characteristics such as soil organic matter (SOM), slope, and soil drainage class were derived from digital soil maps available from the Iowa Cooperating Soil Survey (Iowa Cooperating Soil Survey, 2003).

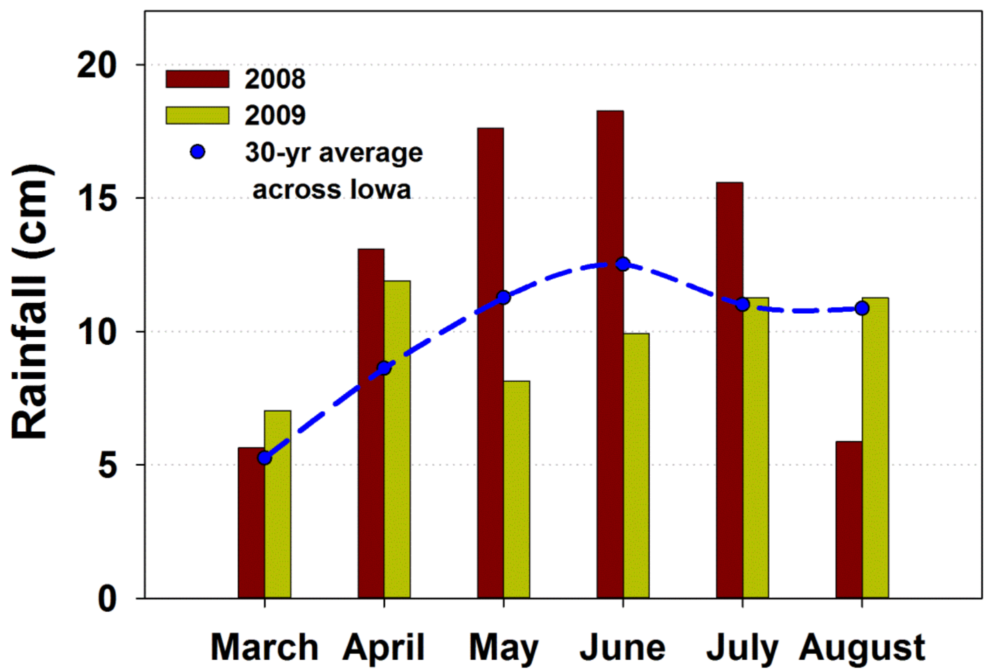

Figure 4. Average monthly rainfall for on-farm trials evaluating two herbicide treatments on soybean in 2008 and 2009.

Hierarchical models with Bayesian statistics were used to identify effects of field-level factors such as average monthly and cumulative rainfall and within-field factors such as SOM, slope or soil drainage class on YD between R+G and G2 herbicide treatments. Hierarchical analysis deals with random variability observed at different levels, and in Bayesian statistics prior distributions are assigned to parameters of distributions to represent knowledge of possible values of these parameters before the data are observed (Gelman et al., 2004; Gelman and Hill, 2007). The observed data are then used to update that knowledge using posterior distributions of parameters. In other words, Bayesian statistics helps to answer the question: “What are the underlying probabilities of observing a range of YD between two herbicide treatments in new situations after collecting and observing data from on-farm trials?” For more details about using Hierarchical models for analyzing data collected from on-farm trials see Kyveryga et al., (2010).

We used posterior predictive distributions of field level means to predict a mean YD for a field that was not studied or observed. We also estimated the probability of yield loss from R+G treatment using posterior predictive distributions. Posterior distributions were obtained by using Markov Chain Monte Carlo simulation method with 10,000 runs.

A mean YD < -100 kg ha^{-1} (<-1.5 bu/acre) was considered as an economic yield loss from R+G treatment because, in general, the treatment with Extreme cost about \$45-50 ha^{-1} (\$18-20/acre) more than that of G2 treatment. Ninety percent credible intervals for posterior mean YD were estimated using 5th and 95th percentiles of the simulated data.

RESULTS AND DISCUSSION

Parameters of posterior distributions of yield difference (YD) between a treatment with Extreme residual herbicide followed by one application of glyphosate (R+G) and a treatment with two post-emergence applications of glyphosate (G2) are shown in Table 1. Posterior regional means represent expected YD across the state in 2008 and 2009 or expected YD between two categories of trials based on site-specific cumulative March through June rainfall observed in 2008 and based on visual differences in the soybean canopy reflectance of color (blue, green and red bands) digital aerial imagery taken in late August of 2009.

Across Iowa, the R+G treatments yielded only 20 kg ha^{-1} less than G2 treatments in 2008 and 10 kg ha^{-1} less in 2009. As confirmed by posterior 90% credible intervals, in each year YD ranged from about -30 to 60 kg ha^{-1} and were not statistically different between the treatment within each year and between the two years of the study. These data indicate that the substitution of one glyphosate application for one application of residual herbicide did not decrease significantly soybean yield. On average, however, the R+G treatment cost about \$45-50 ha^{-1} (\$18-20 /acre) more than G2 applications, which corresponds to about 100 kg ha^{-1} of additional of soybean yield needed to cover the cost of Extreme herbicide. This analysis accounts only for the current level of resistance and does not account for future resistance problems that may result in much larger economic losses.

Among and within-field variation in YD are shown by posterior regional and within field standard deviations (SD) (Table 1). Within field variability in 2008 was about five times larger than that in 2009. One explanation for this difference could be a larger number of trials conducted in 2009 than in 2008, or the effects above-normal rainfalls in 2008. In 2008 for the studied locations, average monthly rainfalls from April through July were about 30-50% higher than the long-term monthly average rainfalls across Iowa (Fig. 4). Visual observations of digital aerial imagery also confirmed numerous flooded and replanted areas within some of the trials in 2008, which likely contributed to a larger within field variability in YD between the two herbicide treatments.

In 2008, some trial locations received twice the normal amount of rainfall in spring and early summer. As a result, four soybean fields that had March through June rainfalls > 50 cm (a long-term state average is from 30 to 40 cm) had a posterior mean YD between R+G and G2 treatments of about -100 kg ha^{-1} (Table 1). This yield loss from residual herbicide was about 40 kg ha^{-1} less than for a category of four trials that had March through June rainfalls < 50 cm. Although the 90% credible intervals for these two categories largely overlapped, these data suggest small yield losses from residual treatments when excessive rainfall promotes weed growth and higher than normal weed population or causes longer than expected delay in the second glyphosate applications. Additional analysis also showed relatively high negative correlations between field level mean YD and April (r=-0.42) or May (r=-0.43) rainfall across eight trials in 2008, indicating a small yield disadvantage from the residual herbicide in high

Table 1. Posterior regional means, average regional among field and within field standard deviations (SD) for soybean yield difference (YD) between a treatment with Extreme residual herbicide followed by one application of glyphosate (R+G) and a treatment with two applications of glyphosate (G2) in 8 on-farm trials in 2008 and 20 trials in 2009.

Variable	Regional or categorical mean YD	Average SD	
		Regional	Within field
	--------------------- kg ha^{-1}	-----------------------	
Year			
2008	-20 (-11, 60) [¶]	120	190
2009	-10 (-26, 59)	108	38
		2008	
March through June rainfall[§]			
<50 cm	62 (-67, 193)	109	150
>50 cm	-103 (-230, 26)	108	2
		2009	
Visual differences on late-season imagery			
No	-10 (-26, 67)	2	12
Yes	-5 (-21, 115)	140	21

[¶] In parenthesis are 90% credible intervals.

[§] Long-term average monthly March through June rainfalls across Iowa ranges from 30 to 40 cm.

On average, R+G herbicide treatment cost about \$45-50 ha^{-1} (\$18-20/acre) more than G2 treatment.

rainfall environment. These yield losses, however, were much smaller than some farmers anticipated at the beginning of this study based on their visual observations.

The risk of a yield loss from substituting one glyphosate application on a residual herbicide in fields received variable early season rainfall could be estimated by simulating posterior predictive distributions of YD for the high and low categories of cumulative rainfall from March through June observed in 2008 (Fig. 5). These distributions show expected field-scale mean YD in fields that were not studied or observed. The additional cost of residual treatment was expressed as 100 kg ha^{-1} of soybean yield. A YD of -100 kg ha^{-1} was considered as an economic loss. On the Y axis, the risk is estimated by subtracting the probability of receiving a YD of <-100 kg ha^{-1} from 1. For the high category of March through June rainfall, the probability of a YD < -100 kg ha^{-1} was about 0.5 while that for the low category of spring rainfall was 0.15. Therefore, fields receiving > 50 cm of rainfall were about 3 times more likely to have an economic yield loss from the residual treatment than those receiving < 50 cm of cumulative from March through June rainfall.

Visual observations of late-season digital imagery often showed distinct differences in the soybean canopy between the two herbicide treatments in 2009 (Fig. 2). In 11 trials, strips with R+G treatments looked darker on the imagery than strips with G2 treatments. Farmers also reported darker areas within R+G treatments in some trials earlier in the season due to the soybean canopy being affected by post-emergence applications of the residual herbicide and expected a relatively large YD between the two treatments. But, posterior regional mean YDs for the category of trials with and without visual differences on the imagery were the same (Table 1). Looking at visual differences in the imagery only, among trial variability where there were visual differences was substantially larger between the two treatments than in trials where there was no visual difference. The soybean canopy damage/burns from the residual treatment delayed soybean maturity but these differences did not lead to significant soybean yield losses.

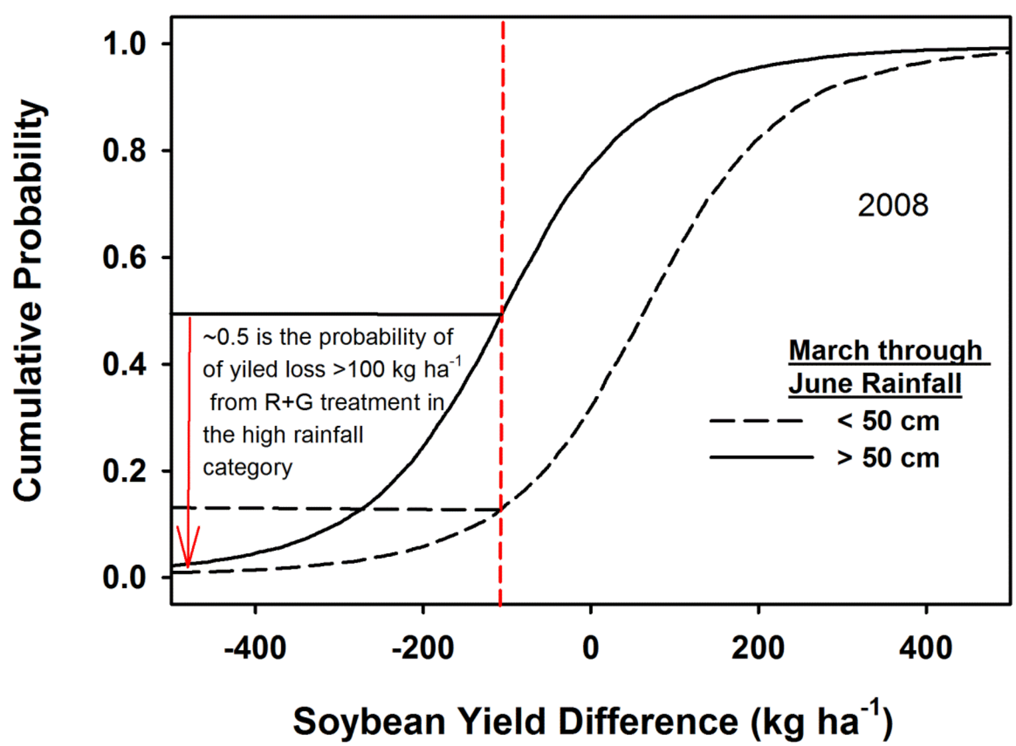

Figure 5. Field level posterior predictions of soybean yield differences (YD) between a treatment with Extreme residual herbicide and follow-up application of glyphosate (R+G) and a treatment with two applications of glyphosate (G2) for two categories based on cumulative March through June rainfall observed in 2008.

Additional analyses using hierarchical models for data collected in both years showed that within field level factors such as SOM, slope or soil drainage class had no effects on YD. Although farmers often reported higher weed pressure and visual symptoms of soybean plant damage in the R+G treatments, spatial variability in soybean YD was relatively unimportant in this study.

CONCLUSIONS

Based on eight on-farm trials in 2008 and 20 trials in 2009, substituting one glyphosate application in a typical two-glyphosate application (G2) system with a residual herbicide, Extreme, did not have a significant effect on soybean yield. Within field variability in YD between R+G and G2 treatments, however, was slightly larger in a relatively wet 2008 than in relatively normal 2009.

In 11 trials in 2009, the R+G treatments showed darker strips on the digital aerial imagery of the soybean canopy, indicating areas damaged from later (post-emergence) than recommended (pre-emergence) applications of Extreme herbicide. But these differences in the soybean canopy were not expressed as large yield losses from the residual herbicide.

Fields receiving > 50 cm of cumulative March through June rainfall in 2008 were about 3 times more likely to have an economic soybean yield loss (>100 kg ha^{-1}) from using the residual herbicide than those receiving < 50 cm of early season rainfall.

Counting weed population densities and identifying weed species during each year would provide additional insight into where and when the largest yield advantage or loss from the residual herbicide occured. Despite these disadvantages, on-farm studies using precision agriculture technologies should help farmers find better alternative systems for glyphosate weed management and quantify the potential economic loss or benefits from reduced glyphosate applications on soybean.

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