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# Use of Unmanned Aerial Vehicles to inform Herbicide Drift Analysis

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**Abstract.** A primary advantage of unmanned aerial vehicle-based imaging systems is responsiveness. Herbicide drift events require prompt attention from a flexible collection system, making unmanned aerial vehicles a good option for drift analysis. In April 2015, a drift event was documented on a Mississippi farm. A combination of corn and rice fields exhibited symptomology consist with non-target injury from a tank mix of glyphosate and clethodim. An interesting observation was the corn, which was glyphosate-tolerant, was injured only by the clethodim; the rice, which was not glyphosate-tolerant, was mostly injured by the glyphosate. This provided two different outcomes from a single drift event. Over 700 acres were impacted, the majority of which was corn. Injury was apparent six days after application. In addition to on-the-ground assessments, an unmanned aerial vehicle was used to collect aerial imagery over affected fields on multiple occasions. Drift plumes were evident in images collected approximately three weeks after application, and in subsequent images; this coincided with peak injury symptomology observed on-ground. Although plants visually recovered, reduced stands and delayed maturity translated into yield reductions between 16 to 40% based on yield monitor data comparisons from affected vs. unaffected portions of each field; these losses were assigned an economic value based on market prices for corn and rice. Unmanned aerial vehicle-based imagery enabled a full characterization of injury extent. These data were coupled to more traditional forms collected by producers to better support their claim of negative impact, and also to rapidly and fully assess the herbicide drift event. Limitations of the unmanned aerial vehicle were related to tradeoffs between spatial resolution and time to collect. Because the extent of the damage was quite large, a compromise was necessary to find a spatial resolution which would provide needed information but which could be obtained within a reasonable amount of time. For a production environment, the issue of battery life and number of batteries necessary to overfly the area become significant. The application of an unmanned aerial vehicle to this real-world problem resulted in an improved outcome for the producer and more supporting evidence for the insurance company.

***Keywords.*** *Corn, clethodim, glyphosate, herbicide injury, herbicide drift, non-target application, Oryza sativa, rice, unmanned aerial systems, unmanned aerial vehicle, Zea mays*

## Introduction

Use of remote sensing to detect herbicide injury is not a new idea. Previous attempts have been made to use both satellite (Prince 2001) and aerial (Huang et al. 2010; Ortiz et al. 2011; Dicke et al. 2012; Huang et al. 2015) platforms, in addition to field-based sensing (Henry et al. 2004; Thelen et al. 2004) to quantify extent of injury to a variety of field crops. Identification of appropriate techniques to enhance detection of within-field variability and quantification of level of injury have presented challenges for researchers working in this area (Ortiz et al. 2011). Satellites were found to offer much too coarse spatial resolution for examining injury (Prince 2001), but aerial platforms were shown to be useful in this endeavor (Ortiz et al. 2011). Thelen et al. (2004) found aerial imagery to be superior to ground-based radiometers for herbicide injury detection, but noted that frequently overcast weather conditions in the Northern Corn Belt could be a practical limitation for acquiring timely data. In agriculture, certain crop stressors require immediate and targeted attention. Failure to quickly react to these stressors can lead to yield impacts, additional inputs, and ultimately economic hardship. Herbicide drift events require prompt attention, making unmanned aerial vehicles a good option for drift analysis. The need to document damage and observe differential plant development necessitates use of some form of imaging; UAVs have the advantage of being more flexible in their timing and application than other platforms such as satellites and airplanes.

## Overview of the Case Study

In April 2015, a drift event was documented on a Mississippi farm using a combination of field data collection and airplane- and UAV-based imagery. The drift plume affected both corn (*Zea mays* L.) and (*Oryza sativa* L.) rice fields. Injury resulted from non-target application of a tank mix of glyphosate and clethodim. Over 700 acres were impacted, the majority of which was corn. Injury was apparent six days after application. Worth noting is that the injury was paired such that the rice was damaged by the glyphosate, while corn was damaged by the clethodim. Another interesting observation, which was highlighted by imagery and confirmed by yield monitor data, was that a portion of one field was protected from off-target deposition by a row of trees. The case study presented is covered by a non-disclosure agreement. Accordingly, certain details about this event are not included in this paper. All still photos taken in the field and used as figures were provided by the anonymous producer who has collaborated with Mississippi State University.

### Site information

The major commodities grown by producers in this area of Mississippi include corn, soybeans (*Glycine max* (L.) *Merr.*), cotton (*Gossypium hirsutum* L.), and rice. Glyphosate-tolerant gene technologies became available to producers in the mid-1990s for corn, soybeans, and cotton, but not for rice. This has left rice susceptible to frequent glyphosate drift injury from neighboring fields since the majority of weed management systems have evolved to become heavily dependent on multiple applications of glyphosate. Huang et al. (2015) reported that in 2011, 55 of 71 reported drift cases in Mississippi were due to glyphosate. Davis et al. (2011) also reported that of 61 complaints filled with the Arkansas State Plant Board in 2006, 40 were glyphosate injury on rice. This situation is consistent across all states in the southern rice region, including Mississippi (Huang et al. 2015), Arkansas (Davis et al. 2011), and Louisiana (Hensley et al. 2013). The highly variable alluvial soils of the region which borders the Mississippi Rivers allow for diversity of planting such that neighboring fields are often planted next to fields planted with different crops, with different weed management needs and practices.

## Herbicide information

### *Glyphosate*

Glyphosate is a non-selective, broad spectrum herbicide used to control a variety of annual and perennial plants including grasses, sedges, broadleaf weeds, and woody plants. Glyphosate inhibits 5-enolpyruvyl-shikimate-3-phosphate synthase, which leads to depletion of key amino acids necessary for protein synthesis within the plant (Sensemen 2007). One of the most recognizable names in weed control, glyphosate is sold as Roundup, among other trade names.

**Figure 1. Rice affected by non-target application of glyphosate in case study field**

Symptoms of non-target application of glyphosate to young rice include chlorosis, leaf mortality, and stunting. These symptoms were seen in affected rice fields (Figure 1). Previous authors have investigated the response of rice to low rates (Davis et al. 2011) and low carrier volumes (Hensley et al. 2013) of glyphosate. Plant height, flag leaf length, prolonged maturity, and yield losses were seen by Davis et al. (2011) at all evaluated application timings (three- to four-leaf, panicle initiation, and boot) at 1/2x and 1/4x rates. Additional researchers have shown that drift applications of glyphosate to rice reduced yield when applied at additional growth stages, including two- to three-leaf (Ellis et al. 2003), panicle differentiation (Ellis et al. 2003; Hensley et al. 2013), one tiller (Hensley et al. 2013) and mid-tiller (Kurtz and Street 2003). Plants that were not killed by glyphosate drift exhibited less visual injury over time, with the worst injury displayed between 10 and 21 days after occurrence of the drift event. Plants that survived the drift event recovered visually to some extent over time. However, plant stands in affected areas were reduced and maturity was delayed by several days.

*Clethodim*

Clethodim is a selective post-emergence herbicide used to control annual and perennial grasses in a wide variety of broadleaf crops, including soybeans and cotton. Trade names for clethodim include Select and Cletodime. Corn is very sensitive to the class of herbicides, labeled as ACCase inhibitors, of which clethodim is included. In fact, clethodim is advocated as a control for volunteer glyphosate-resistant corn (Currie 2010; Terry et al. 2012), achieving up to 96% control (Terry et al. 2012), indicating that corn is particularly sensitive to this herbicide. The worst injury was seen two to three weeks after injury was noticed. Dead growing points on corn were typical of clethodim injury to corn and were noted by the producer; white to purple streaks on the leaves were also noted (Figure 2). Corn present in the most severely affected fields had mortality at 10 days after injury was apparent. In stands that did not die, growth was visibly stunted. Sixteen fields were affected for a total of over 500 acres.

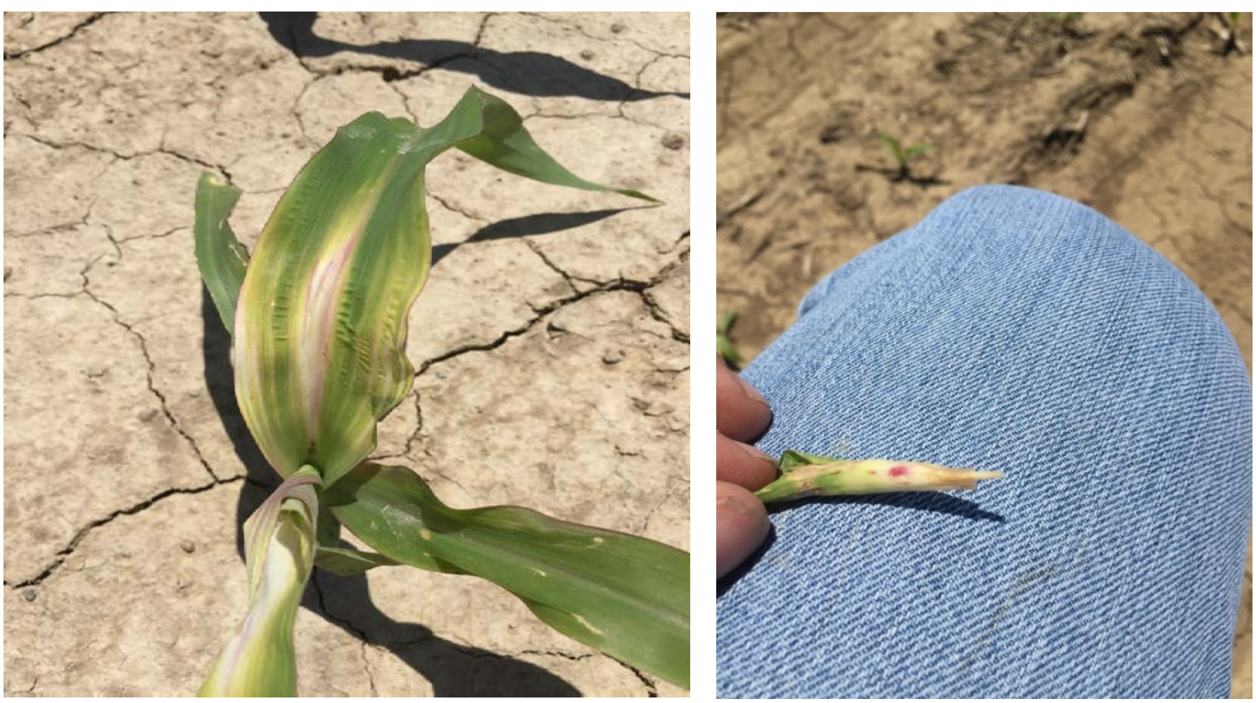

**Figure 2. Corn affected by non-target application of clethodim observed in case study field.**

## Supporting data collection

Henry et al. (2004) provided two steps in assessing herbicide drift cases. The first step is determining what herbicide is the causal agent of injury. Tissue samples were collected between two and three weeks after the drift event from four fields to test for presence of glyphosate and clethodim. Both chemicals were found in all corn tissue samples. Rice tissue samples also tested positive. The producer had not yet made his own applications of any postemergence herbicide to the farm; thus there was no possibility of residual from his own application. The second step identified by Henry et al. (2004) is determining the status of the crop. Although frequent claims to insurance companies are related to herbicide-induced injury, producers face difficulty assessing the percentage of acres impacted by drift to the degree of injury (Ortiz et al. 2011). This is one area where imagery, either aerial or UAV-based, can provide supporting data. Previous research has how that remote sensing at low-altitudes can indirectly assess the effects of glyphosate drift (Ortiz et al. 2011). However, there are limits to the information which can be provided; optical remote sensing was not effective at accurately estimating herbicide application rate across a broad range of field and weather conditions in a study by (Thelen et al. 2004).

Aerial photos were taken by the producer ten days after application (Figure 3). UAV imagery was collected on multiple occasions, with the first flight approximately three weeks after application (Figure 4). Additional flights were made at eight (Figure 5), nine, 12, and 16 weeks after application. This allowed the producer to have some preliminary information about the extent of the damage. Additionally, weather data were obtained to examined wind directions and speeds during the time frame of suspected application. This data were used by the responsible agencies to determine the responsible party and begin the process of retribution.

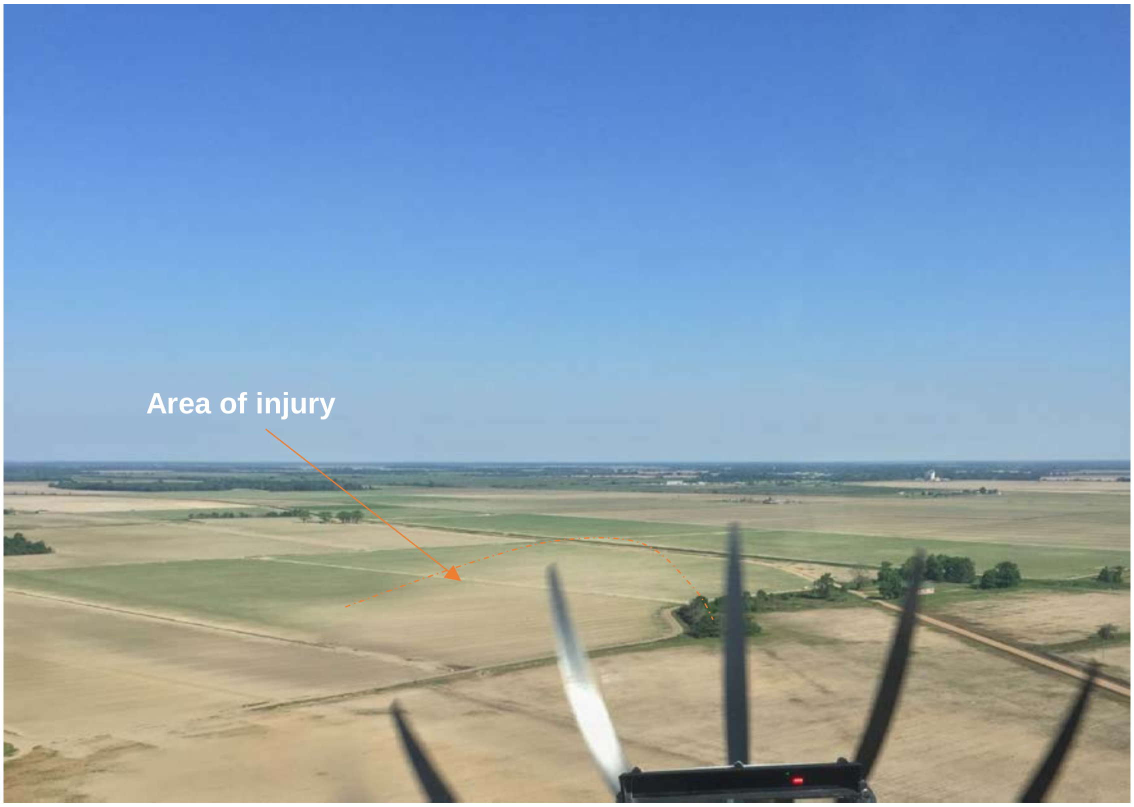


**Figure 3. Aerial photo taken approximately ten days after drift event onto corn fields**

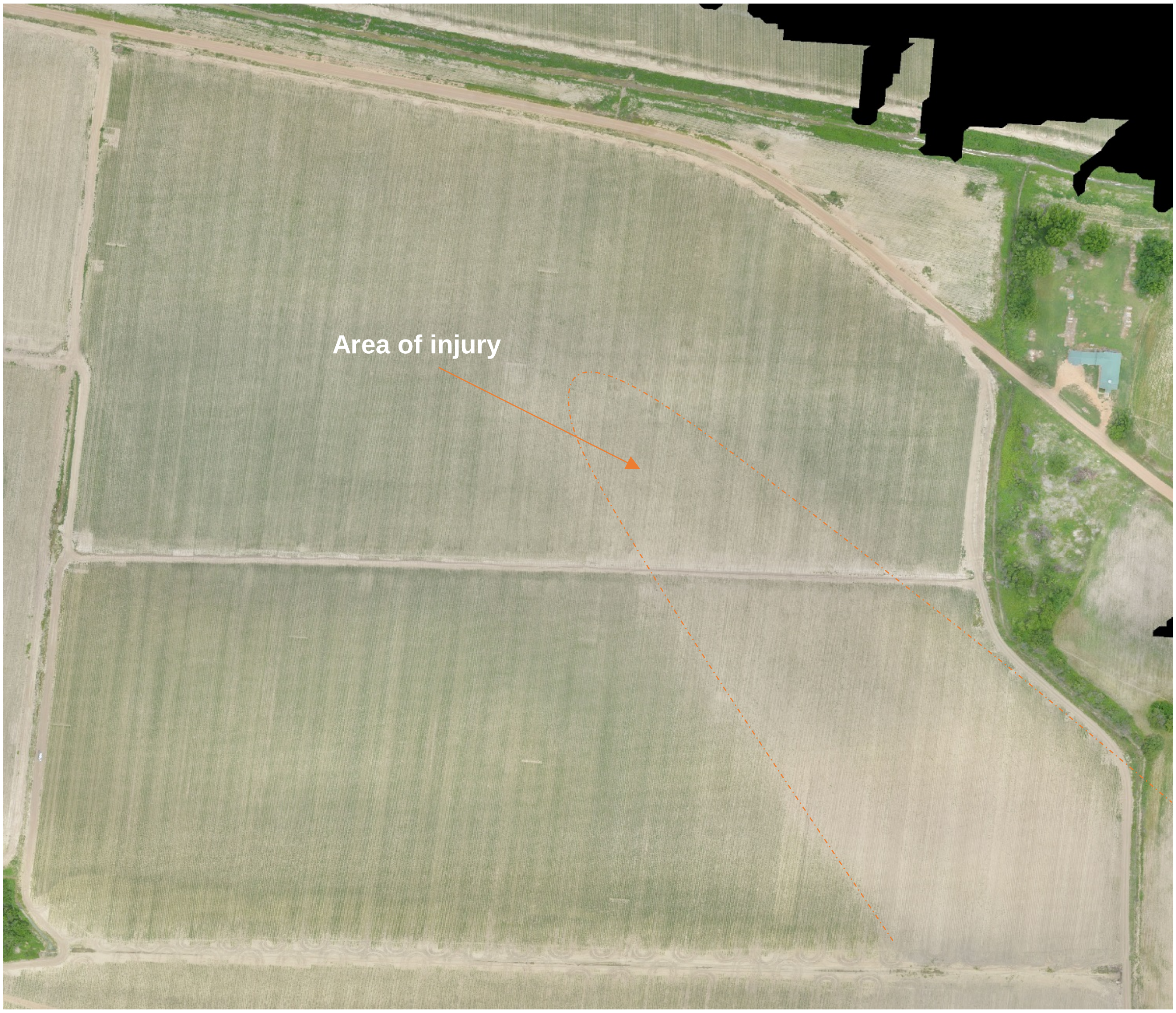


**Figure 4. UAV imagery collected over some of the severely injured corn fields showing the drift plume**

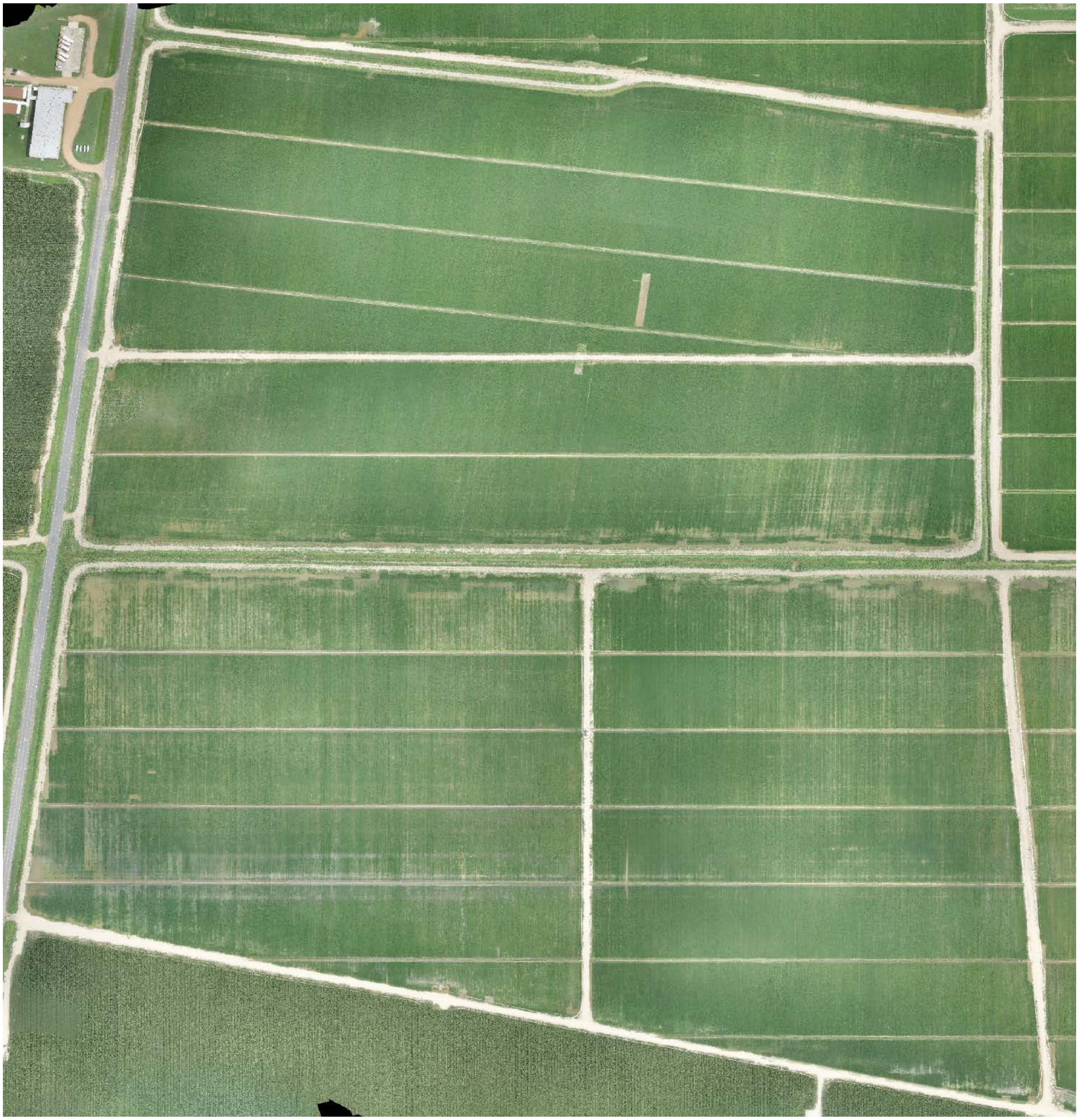

**Figure 5. UAV imagery collected over injured rice eight weeks after drift event.**

Replanting decisions can be quite complex and a number of additional considerations come into play. Competition among corn plants of uneven growth and overpopulation of corn can both negatively affect yield (Terry et al. 2012). The producer in this study managed damaged fields with the same practices applied to non-damaged areas lieu of replanting. Although crops may not show extensive herbicide injury, yield may still suffer (Henry et al. 2004). Davis et al. (2011) observed that a 1/2x rate of glyphosate on rice at the boot stage exhibited only 10% visual injury at three weeks after treatment but resulted in 80% yield loss. Undetected yield reductions decrease profitability because a producer may continue to apply inputs to a crop with reduced yield potential (Hensley et al. 2013). Yield monitor data provided the basis for calculations of yield reduction between damaged and non-damaged areas (Figure 6). Yield reductions between 16 and 40% were seen for affected fields. Although rice exposed to varying degrees and types of stress such as herbicide injury can have reduced milling quality, no milling quality losses were observed for any rice harvested from any field.

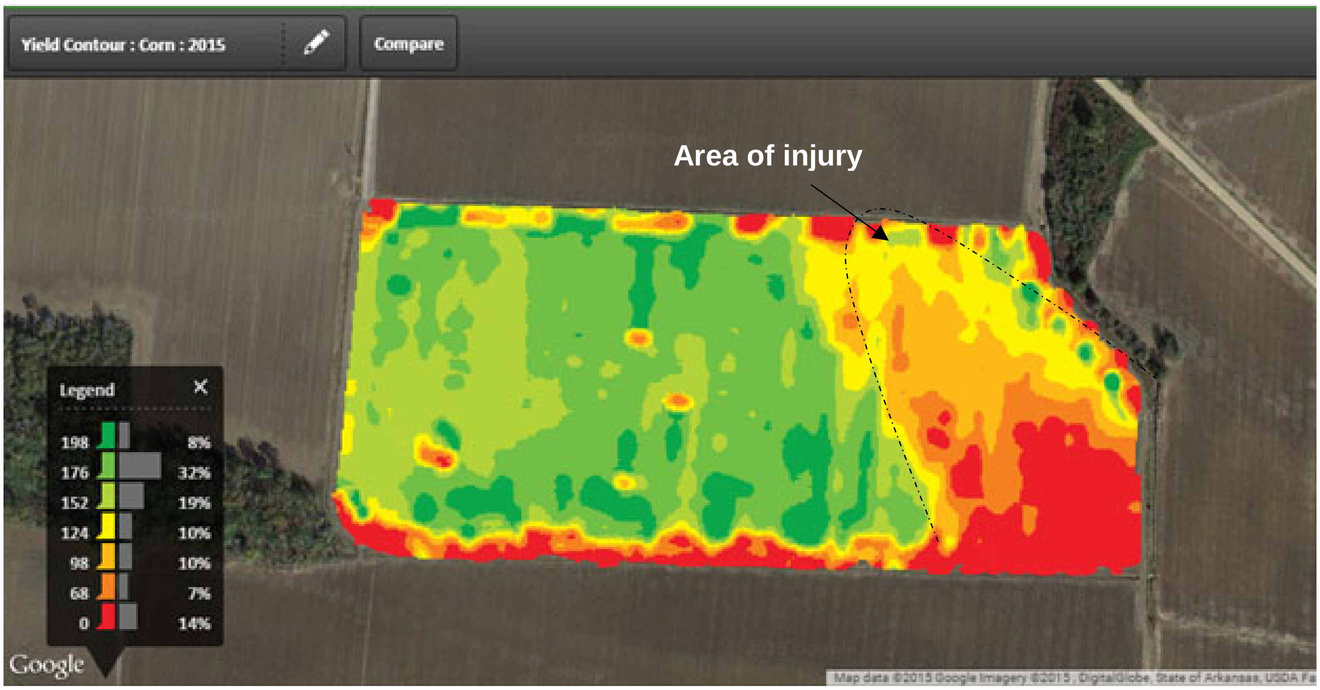


**Figure 6. Yield map from severely injured corn field with visible yield reductions in the area of the drift plume**

## Limitations

Limitations of the operation of the unmanned aerial vehicle were related to tradeoffs between spatial resolution and time to collect. Higher altitude flights stretch battery life and provide more areal coverage in a shorter time frame, but come at a cost to spatial resolution. Depending on the size of target plants, spatial resolution may be more or less of an issue. Because the extent of the damage in this case was quite large, a compromise was necessary to find a spatial resolution which would provide needed information but which could be obtained within a reasonable amount of time. For a production environment, the issue of battery life and number of batteries necessary to overfly the area become significant; battery concerns which forced the researcher to prioritize which fields would be overflown.

Although imagery can be used to detect injury and quantify area affected, currently it is not possible to estimate dose or identify the causal agent without additional field work. Moreover, previous researchers (Koger et al. 2005; Davis et al. 2011) have noted that herbicide injury is variety specific. Dicke et al. (2012) concluded that soil effects may have confounded their ability to assess herbicide injury to corn with remote sensing. This could make rating curves difficult to generate because of the specificity in application that would result.

## Conclusion or Summary

Herbicide drift is an inevitable occurrence is many production areas. The shift to glyphosate-tolerant systems has non-resistant crops at a disadvantage. As new herbicide technologies and resistance genes are released into the market (e.g., Enlist), this trend will likely continue. New tools for producers to rapidly assess crop status and extent of damage will allow them to make more informed decisions about replanting and also provide proof of economic damages for insurance purposes. Unmanned aerial vehicles have the advantage of being deployed in a timely fashion to capture injury at crucial points; this flexibility may not exist for other platforms such as aerial or satellite systems. However, battery life issues and acreage become additional factors which weigh into feasibility of use.

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