Assessing Soybean Injury from Dicamba Applications Using Multispectral Imaging on a Small Unmanned Aerial Vehicle (48-2019)

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Background and Objectives

Intensive use of glyphosate has exerted a high selection pressure on weed populations, resulting in the evolution of 10 glyphosate-resistant weed species in Mississippi. Dicamba is another herbicide used for POST control of several broadleaf weeds in corn, grain sorghum, small grains, and non-cropland. Dicamba-tolerant (DT) soybean is commercially available now. DT crops provide new options to combat weeds resistant to glyphosate. Upon commercial launch of DT-trait soybean, off-target dicamba drift from routine use in DT crops onto susceptible crops became a major concern. The research farms of USDA ARS at Stoneville, Mississippi encountered very serious herbicide damages in two years consecutively from a neighboring farmer's field where DT soybean had been planted and the drift from applications of dicamba spread out over the area. It can be predicted that, with more adoption of DT cropping systems, the concern would be much greater with significantly increased numbers of dicamba drift complaints.

Unmanned aerial vehicle (UAV) is a unique platform for obtaining field-level vegetation data with ultra-high spatial resolution (a few centimeters to millimeters per pixel) imagery through the flight at ultra-low altitudes (tens of meters to a few meters). A portable GPS-controlled digital camera or a multispectral imager mounted on a small UAV can overfly a soybean field and quickly determine crop injury induced with different dicamba spray rates at different soybean growth stages. This information can be provided as guidelines for Mississippi soybean producers and consultants to assess and reduce the loss caused by the unwanted dicamba.

This project developed a UAV digital and multispectral imaging system aiming at assessing non-DT soybean injury from dicamba sprayed at different growth stages and rates to evaluate the feasibility of this technique. This project also produced a protocol for how UAVs and multispectral imaging sensors can be used by soybean producers and consultants to effectively assess soybean injury from dicamba in fields for guideline data for them to assess and reduce the loss caused by the unwanted dicamba.

Project Objective:

1. To install, configure and evaluate a spray system for spraying dicama at different rates for the experiment to assess soybean injury
2. To develop a GPS-enabled multispectral imaging system on a small UAV to fly over the soybean field at different growth stages
3. To process and analyze the image data acquired with eventual yield to determine the losses from different growth stages

Report of Progress/Activity

Objective 1: To install, configure and evaluate a spray system for spraying dicama at different rates for the experiment to assess soybean injury

A four-row hooded spray boom was mounted on a tractor equipped with Tee Jet 4003 standard flat-spray nozzles delivering 140 Lha^{-1} of water at 193kPa (Fig.1). The three baskets on the top of the spray booms can hold dicamba at different concentration rates. The system can automatically switch between them to spray different concentrations of dicamba for the experiments in this project. This complete dicamba spray system was installed, configured and tested to spray different rates of dicamba at 0.0X, 0.05X, 0.1X, 0.5X and 1.0X (X=12.8 oz/ac with Engenia® (BASF Corp., Florham Park, NJ)) for the experiments.

Objective 2: To develop a GPS-enabled multispectral imaging system on a small UAV to fly over the soybean field at different growth stages

For the project in 2018 a GPS-enabled MicaSense RedEdge-M camera (Fig. 2 (a)) was mounted and set up on a DJI Phantom 4 Pro small drone (Fig. 3 (a)) to collect the aerial images for the experiments in the project. This camera has 5 lenses. They are all narrowband for near-infrared, red-edge, red, green and blue multispectral imaging, respectively. The feature of the camera is that it can be directly connected to a downwelling light sensor (DLS) which is a 5-band incident light sensor corresponding to each of the camera sensors. The DLS measures the ambient light during a flight for each of the five bands of the camera and records this information in the metadata of the TIFF images captured by the camera. This information can then be used by specialized processing tools (like Pix4Dmapper) to correct for global lighting changes in the middle of a flight, such as those that can happen due to clouds covering the sun. In this way, the camera can be used with the DLS sensor mounted on a mast with a clear view of the sky, and completely unobstructed so that no part of the aircraft can cast a shadow on the light sensor. However, the DLS is not required in order to use the RedEdge-M camera. Whether flying with or without the DLS, always capture calibrated reflectance panel images before and after each flight.

In early 2019 the UAV imaging system developed in 2018 crashed. So, another GPS-enabled Parrot Sequoia camera (Fig. 2 (b)) was developed for the project in 2019. This camera was mounted and set up on a DJI Phantom 3 Pro small drone (Fig. 3 (b)) to collect the aerial images for the experiments in this project. This camera has 5 lenses. One is for broadband red-green-blue digital imaging. Other four are for narrowband near-infrared, red-edge, red and green multispectral imaging. With the camera a sunshine sensor was attached to allow the system able to analyze plants' vitality by capturing the amount of light they absorb and reflect at the same time.

This study was conducted in a 10-acre soybean field located on a research farm managed by the USDA-ARS Crop Production Systems Research Unit, Stoneville, MS. For this study of soybean injury from dicamba, the field was isolated from outside with 16 row corn plant buffer zones to prevent any dicamba drift going outside. Inside the field 104 row soybeans were planted in 800 ft. In the soybean area three blocks were formed for UAV imaging at the stages V4-V5, R1-R2 and R3-R4, respectively. In each block three 8 rows, which are the treated areas, were separated by 4 rows to reduce interference each other to repeat the image acquisition in the subblocks. Fig. 4 illustrates the experiment field layout with blocks for the dicamba treatment at each stage and in each block the designed dicamba spray doses at different plots.

During the growth period at each growth stage the soybean injury was visually rated and at harvest the yield of the entire soybean area was measured by the AgLeader yield monitor on the combine.

This is a two-year project. In the first year of this project, 2018, in the research farm the 10-acre soybean field were designed with plots to run three experiments with dicamba spray and UAV imaging and field measurements (visual plant injury rating, plant height and plant dry weight) one day, one week and two weeks after treatment. For the first experiment we sprayed on May 31, 2018 and completed UAV imaging and field measurements on June 15. However, in the late morning of June 15 all USDA research farms at Stoneville noticed extensive soybean injury from dicamba, including the experiment field for this project. The injury showed a typical twisting and leaf cupping symptoms (Fig. 5), which made us on hold for continuing further experiments, especially the focus of this project is on the responses of low doses of dicamba.

We were expecting the recovery of the plants. However, the situation was never improved for the designated second and third experiments and some parts were even worse (Fig. 6). So, we decide to and stop any further experiments planned this year and will continue to do it next year to fulfill the goal and objectives of the project.

Therefore, the planned three experiments in 2018 was only conducted at the early growth stage instead of all planned three stages. For the one-stage experiment, in the research farm, an 10-acre soybean field were sprayed with dicamba at 0.0X, 0.05X, 0.1X, 0.5X and 1.0X (X=12.8 oz/ac with Engenia® (BASF Corp., Florham Park, NJ)) and UAV imaging and field measurements (visual plant injury rating, plant height and plant dry weight) one day, one week and two weeks after treatment. The block of the field was sprayed on May 31, 2018 and completed UAV imaging (Fig. 7) and field measurements on June 15. The soybean was harvested on September 15, 2018.

Objective 3: To process and analyze the image data acquired with eventual yield to determine the losses from different growth stages

Fig. 8 shows the measured plant height, shoot dry weight and leaf area related with dicamba spray rates at different times after dicamba treatment. This figure shows that the longer the time after dicamba treatment, the more obvious the decrease trend of measured attributes with the increase of spray rates. Among the three attributes plant height presents the most sensitive response to the spray rate. It shows an obvious decrease trend with increase spray rates even in the same day after dicamba treatment.

To relate the aerial image information to dicamba spray dosage and crop yield, we recalled the data in 2014 with similar experimental design but using the images acquired by a multispectral camera operated on Air Tractor 402B at the altitude about 1,500 ft. Although the image resolution is coarser than the images acquired by the portable multispectral camera on UAV which flied at 100-200 ft over crop canopy, it indicates the required data from remotely sensed images to assess the yield loss from dicamba spraying. This lays a foundation for us to plan and scheme the future research to complete the project.

Fig. 9 shows how NDVI, the most vegetation index calculated from red and near infrared band data in the multispectral images, related to the soybean yield. As the figure shown NDVI is highly “nonlinearly” related to yield regardless weeks after dicamba treatment, which illustrates that NDVI can be ab effective indicator of soybean yield loss. Fig. 10 plots the relationships of dicamba spray rates related to average NDVI over the weeks and the soybean yield. Fig. 11 shows the relationship of soybean yield reduction with the average NDVI over the weeks after dicamba spraying. They are necessary data and tools to determine the soybean yield loss from dicamba spraying at different growth stages.

In the second-year of the project, 2019, we have tried to repeat the same procedure to complete all the three experiments. However, the season in 2019 was very wet and tractor operation was impossible at the times of designed treatment timing. As we originally designed (Fig. 4) we should spray and sample soybean in the field on 6-18-2019 for V4-V5 Stage, 7-9-2019 for R1-R2 stage and 8-20-2019 for R3-R4 stage. Due to continuous precipitation this year the field never provides the conditions for field operations of tractor-mounted sprayer and human plant sampling. So, we first decided to cancel the first experiment on 6-18-2019 and move on to consolidate the experiment plots for the second and third experiments (see Fig 12 for revised experiment design).

However, due to continuous precipitation early this year the field was never provided with the conditions for field operations of tractor-mounted sprayer and human plant sampling at the soybean V4-V5 and R1-R2 stages. At the stage R3-R4, due to the closed canopy with high plant heights, the tractor-mounted sprayer had no sufficient clearance to conduct spraying over the field (Fig. 13). In this way we had to cancel all the planned experiments.

With the experience we thought deeply on how to overcome the weather, field and plant issues for the successful research we decide to further develop to use unmanned aerial vehicle (UAV) to spray over the field with the restrictions from weather, field and plants. We invested about $50,000 and placed the order for a strong UAV spray system (Fig. 14) and expect to put it in use next year to achieve all the goals of this project.

Impacts and Benefits to Mississippi Soybean Producers

In the past decade, most of the soybeans planted are glyphosate-resistant (GR) cultivars. With concomitant increase of GR weeds, other herbicides are more and more used to replace glyphosate some way. Dicamba is such an herbicide for POST control of several broadleaf weeds. Although DT soybean is commercially available and used, the injury to non-DT soybean varieties, such as regular non-DT and Libertylink® beans, is of great concern. Soybean injury from dicamba drift has been complained in Mississippi Delta especially in the last few years. It can be predicted that, with more adoption of DT crop system in the near future, the concern would be much greater with significantly increased numbers of dicamba drift complaints. Multispectral imaging on small UAVs provides a rapid, consistent and accurate assessment of soybean injury from dicamba sprayed at different growth stage and rates to be applied in practice for implementing site-specific weed management strategies in soybean farming. The outcome of this research activity has impact on about 2-million-acre soybean fields in the state of Mississippi, especially those parts planted with various non-DT soybeans.

End Products–Completed or Forthcoming

- Invited to present “Development and Applications of Unmanned Aerial Vehicles: Challenges and Opportunities”, Session A Technical Innovations, the 27th Modern Engineering and Technology Seminar (METS 2018), Taipei, Taiwan, Oct 22 – 24, 2018. p. 29.
- Invited to present “Unmanned Aerial Vehicles for Developing Sustainable Agriculture”, Unmanned Aerial Vehicles for Developing Sustainable Agriculture, Agricultural Drone Awareness Event, Alcorn State University, Lorman, Mississippi, Aug 8-30, 2019. p. 18.
- Invited to present “Aerial Application Technology and Remote Sensing for Developing Sustainable Agriculture”, International Top-level Forum on Engineering Science and Technology Development Strategy—Precision Operating Equipment (ITFESTDS) and International Conference on Intelligence Agriculture (ICIA) jointly held during October 18-21, 2019 in Beijing, China. p. 17.

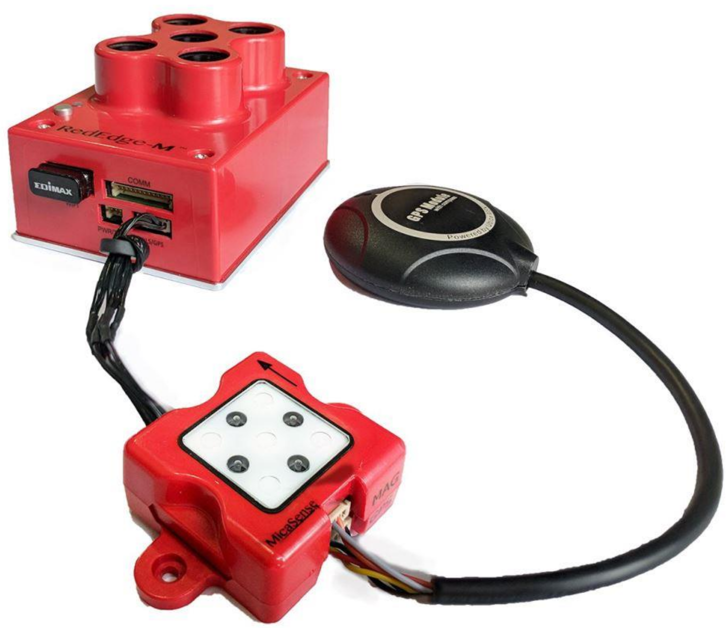
This project has produced protocol for UAVs and multispectral imaging sensors to be used by soybean producers and consultants to effectively assess soybean injury from dicamba in fields and guideline data for them to assess and reduce the loss caused by the unwanted dicamba.

With introducing new spray UAV, a presentation will be made for the findings/results from the new activity (although not received MSBP funding in 2020) as they are developed:

- Y. Huang, K. N. Reddy, J. Zhang. Remote Sensing Assessment of Crop Injury Caused by Off-Target Herbicide Drift. The 15th International Conference on Precision Agriculture, June 28-July 1, 2020, Minneapolis, Minnesota.

Graphics/Tables

Fig. 1. Tractor mounted dicamba spray system.



(a)

(b)

Fig. 2. MicaSense RedEdge-M camera and companion DLS and GPS units (b) Parrot sequoia camera and companion sunshine sensor with GPS.

(a)

(b)

Fig. 3. (a) MicaSense RedEdge-M camera and DLS and GPS set up on DJI Phantom 4 Pro drone (b) Parrot sequoia camera and sunshine sensor with GPS set up on DJI Phantom 3 Pro drone.

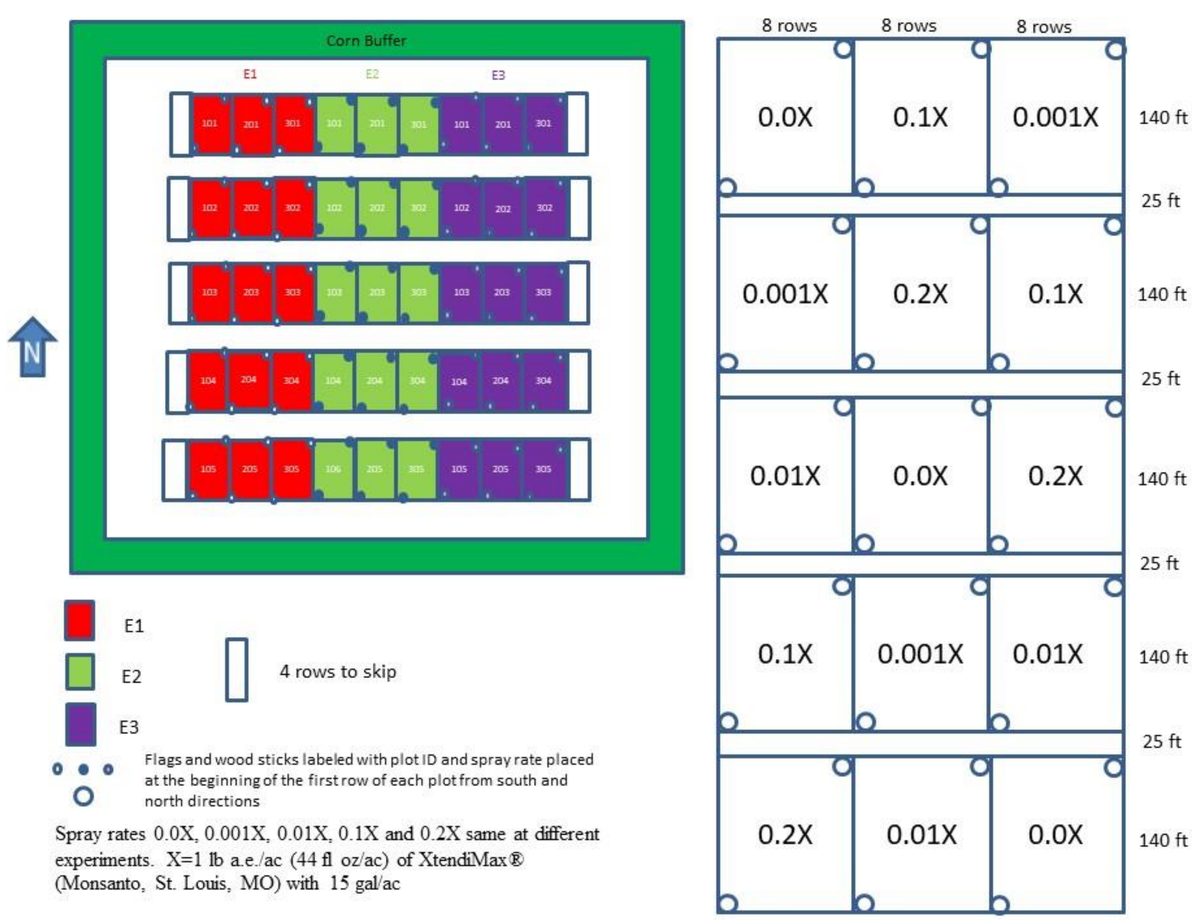
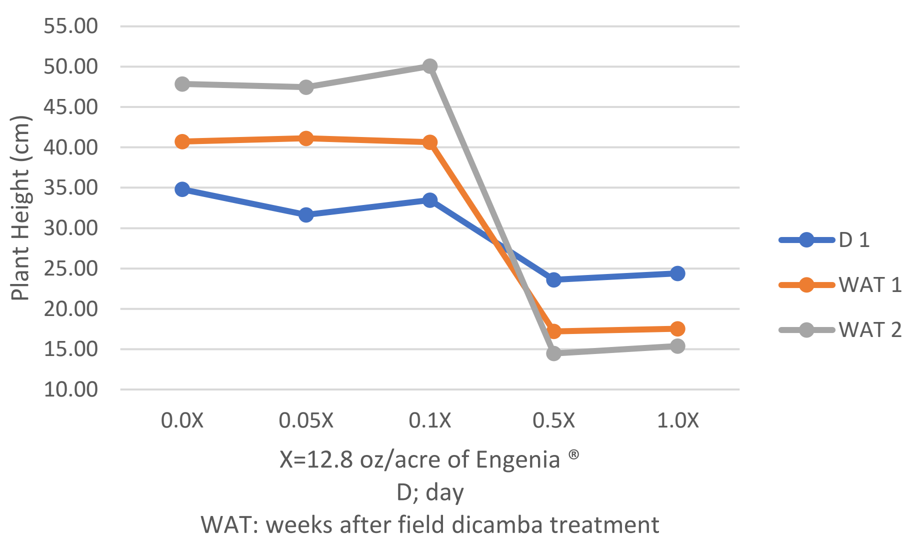


Fig. 4. Experiment field layout and designed dicamba sprays at different plots (E1 is the block for treatment at V4-V5 stage, E2 is the block for treatment at R1-R2 stage and E3 is the block for treatment at R3-R4 stage.

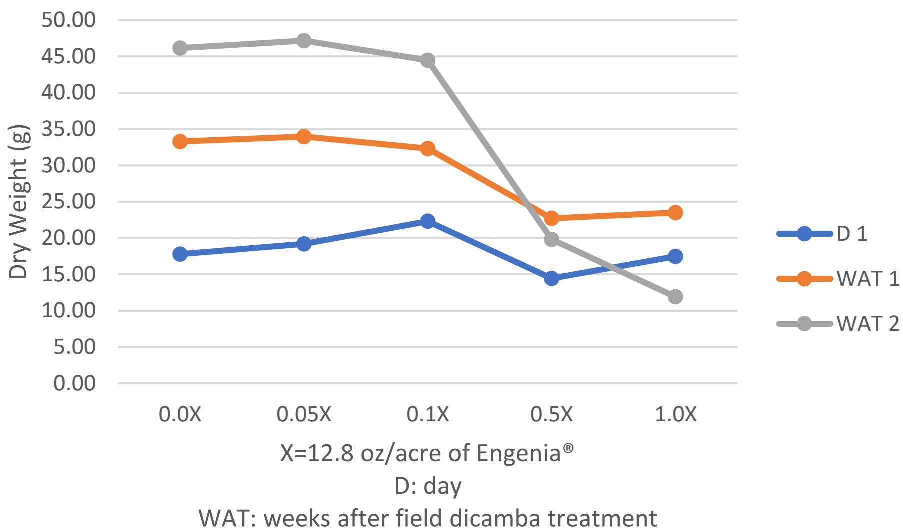
Fig. 5. Twisting and leaf cupping symptoms of soybean dicamba injury in the experiment field due to areawide off-target drift of dicamba.

Fig. 6. Worse situation in late season of 2018.

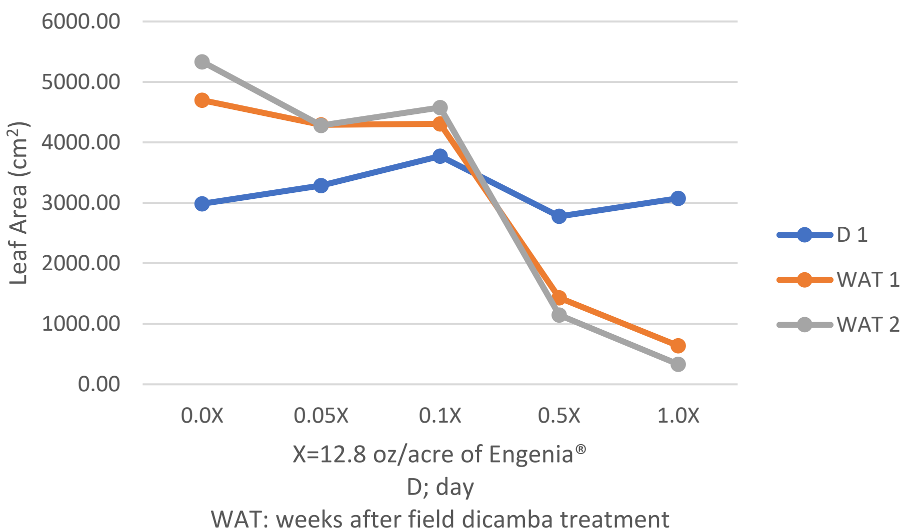
Fig. 7. Color-infrared images acquired from DJI drone at different times after dicamba treatment for the first-stage experiment (conducted at the black rectangle enclosed area).



(a)

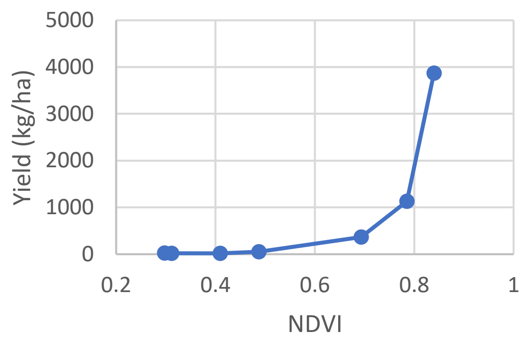


(b)

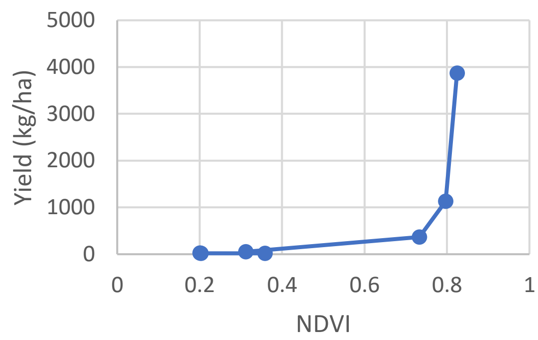


(c)

Fig. 8. Measured plant height, shoot dry weight and leaf area related to dicamba spray rates at one day, one week and two weeks after dicamba treatment.



(a)



(b)

Fig. 9. Relationship between NDVI and soybean yield (1) one week after dicamba spray; (2) three weeks after dicamba spray.

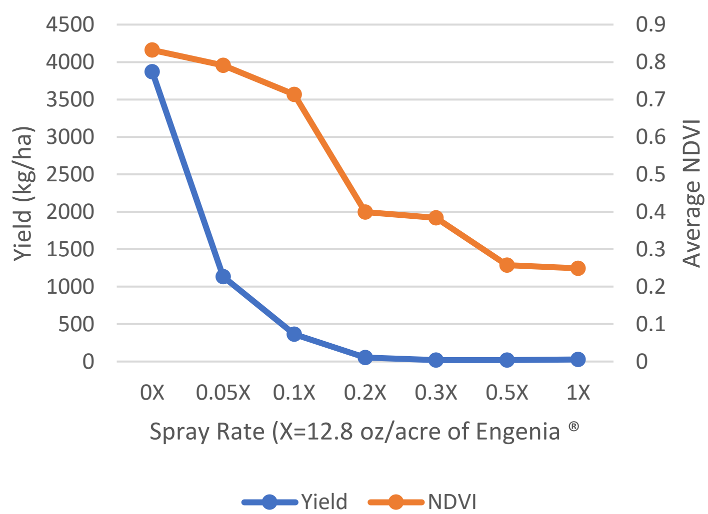


Fig. 10. Relationships between dicamba spray rates with average NDVI and soybean yield.

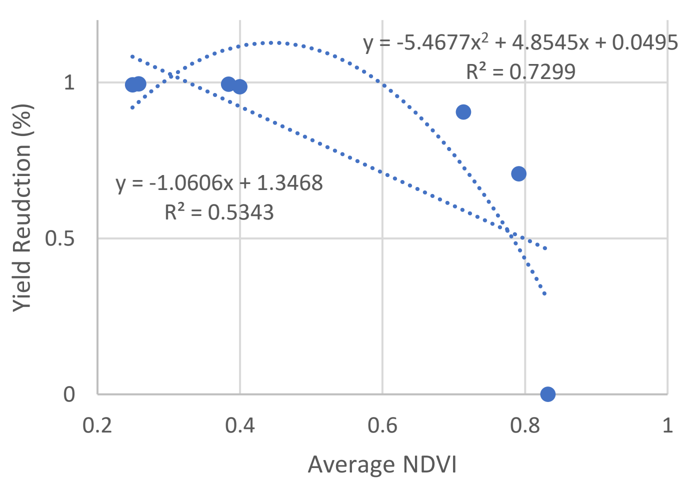


Fig. 11. Relationship between soybean yield reduction and average NDVI.

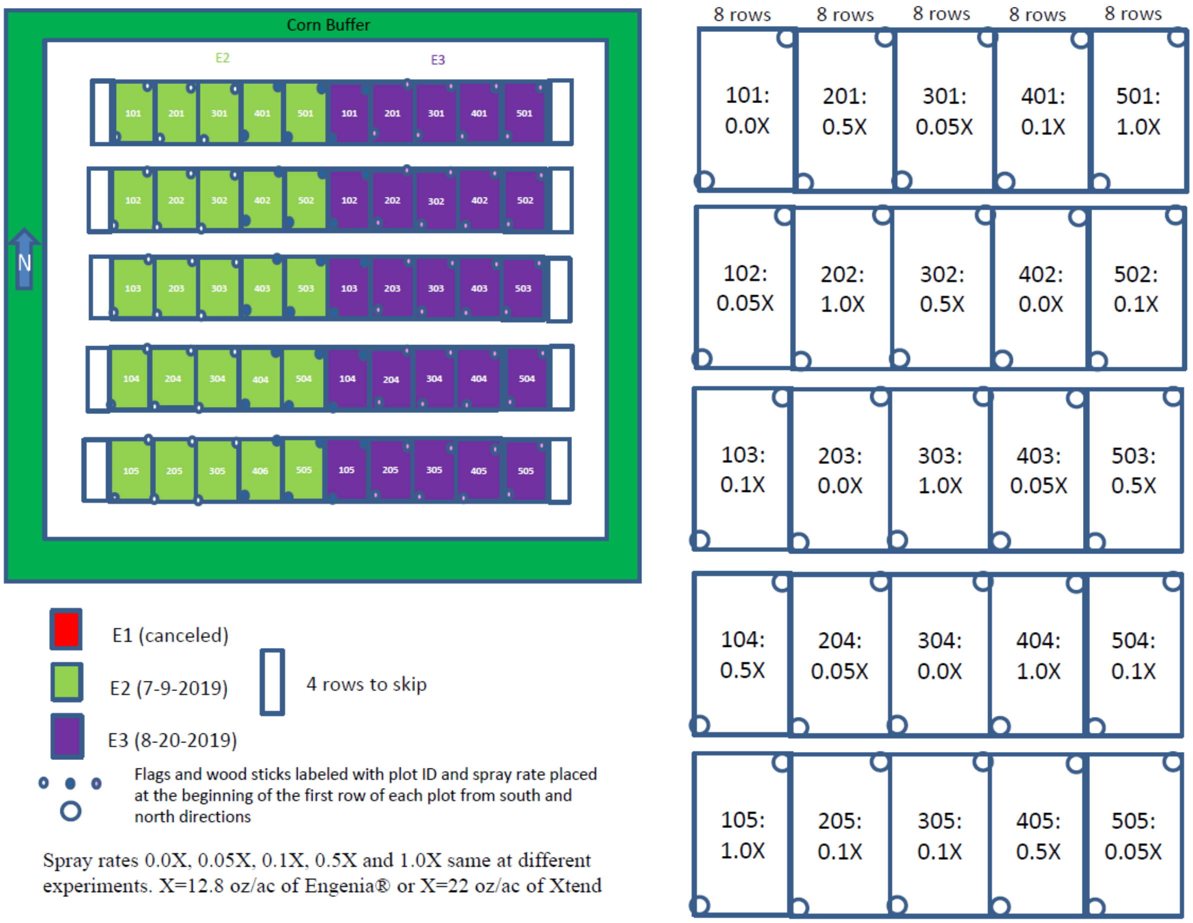


Fig. 12. First revised experiment plan.

Fig. 13. High soybean plants prevent the tractor-mount sprayer from being properly operated.

Fig. 14. Spray UAV we ordered.