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Ground-Based Spectral Reflectance Measurements for Efficacy Evaluation of Aerially Applied Glyphosate Treatments

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Abstract. *Aerial application of herbicides is a common tool in agricultural field management. The objective of this study was to evaluate the efficacy of glyphosate herbicide applied aerially with both conventional and emerging aerial nozzle technologies. A Texas A&M University Plantation weed field was set up in a randomized complete block design with three replicates. Four aerial spray technologies treatments: electrostatically- charged nozzles powered off, electrostatically charged nozzles powered on, conventional flat-fan hydraulic nozzle and rotary atomizers were tested. Spectral reflectance measurements were acquired with a ground-based sensing system for all treatment plots to evaluate glyphosate efficacy and performance of aerial spray technologies. Field measurements were carried out at 1, 8, and 17 days after treatment (DAT). Statistical analyses indicated that glyphosate applied with different methods killed the weeds effectively compared to untreated areas at 17 DAT. Electrostatically-charged nozzles powered on, conventional flat fan nozzles and rotary atomizers had better performance than the electrostaticly charged nozzles powered off. The results provide applicators with guidance for aerial application equipment setups that can result in herbicide savings and optimized applications in other crop.*

Keywords. Aerial application, efficacy, weeds, glyphosate, NDVI.

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Introduction[1]

Glyphosate, a nonselective contact herbicide, is used extensively for weed control in agricultural production systems. Use of glyphosate has increased dramatically due to the introduction of transgenic crop varieties that tolerate over-the-top or directed applications during some growth phases without significant impact on yield and reduced-tillage or no-tillage farming systems. Jordan et al. (1997) evaluated the efficacy of glyphosate alone and in combination with other herbicides, but their work was limited to ground applications. Specialized agricultural aircraft have been developed largely as a result of convenience as they allow for better timing of and greater efficiency in application treatments. Aircraft are able to apply agricultural products, such as herbicides, fertilizer and pesticides, rapidly over large areas. Aerial applications of glyphosate have increased with the requirement for more effective weed management prior to planting spring-seeded crops. Many studies have been conducted to evaluate the performance of aerial spray technologies. For the most part these studies have indicated that optimum spray rate and droplet size combinations vary with pesticide product, pest, and specific crop (Bouse et al., 1992, Hoffmann et al., 1998, and Kirk et al., 1989, 1992, 1998 and 2001). Latheef et al. (2009) investigated the efficacy of different insecticides applied with aerial electrostatic-charged sprays and conventional sprays and found comparable deposition and control between both electrostatic and conventional flat fan nozzles.

Spectral reflectance properties based on the absorption of light at a specific wavelength are associated with specific plant physiological characteristics. The spectral reflectance in the visible wavelengths (400-700 nm) is low because of the high absorption of light energy by chlorophyll. The reflectance of the near infrared (NIR) wavelengths (700-1300 nm) is high because of the multiple scattering of light by different leaf tissues (Taiz and Zeiger, 2006). For example, plant stress usually results in an increase in visible reflectance and a decrease in NIR reflectance. Lamb and Brown (2001) suggested that differences in spectral reflectance between weeds and their background could be used to remotely sense weeds. Detecting weeds against a soil background on fallow ground is a straightforward process as the weeds and soil have significantly different spectral reflectance characteristics in the Red and NIR wavelength bands. It is also well known that the Normalized Difference Vegetative Index (NDVI) is a good indicator of vegetation, crop biomass and health in agricultural applications. NDVI is calculated as: NDVI= (NIR – Red) / (NIR + Red), where Red and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. Healthier crop canopies will absorb more red and reflect more near infrared light than stressed or unhealthy canopies, and consequently have higher NDVI values.

Many on-the-go, ground-based sensors are available for collecting real time spectral reflectance data and calculating NDVI. The Greenseeker® (NTech Industries, Inc., Ukiah, CA) has been widely used for mapping NDVI in a variety of different crops. Martin et al. (2005 and 2007) used this sensor to collect NDVI data at multiple growth stages during the life cycle of corn and evaluate the relationship between NDVI and corn grain yields.

Jones et al. (2007) estimated chlorophyll yield and concentration in spinach by using NDVI values from a Greenseeker sensor and a multispectral imaging system. Freeman et al. (2007) collected Greenseeker senor NDVI values and plant height measurements on individual corn

[1] Mention of trademark, vendor, or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

plants at various growth stages and related them to individual plant biomass, forage yield and N uptake. Flynn et al. (2008) evaluated spatial properties of grassland biomass with Greenseeker sensor NDVI data. A spectroradiometer is also a useful tool for detection and monitoring of crop growing status. Bronson et al. (2005) used Greenseeker NDVI to compare with NDVI values taken by a spectroradiometer to determine which better estimated in-season plant nitrogen (N) status. Darvishzadeh et al. (2008) examined the utility of hyperspectral remote sensing in predicting canopy characteristics by using a spectroradiometer. Zhang et al. (2009) characterized the spatial variation of NDVI derived from spectral reflectance measurement by FieldSpec® (Analytical Spectral Devices, Inc., Boulder, CO) spectroradiometer.

At the time this study was conducted, there were no other studies involved in evaluating aerial application of glyphosate using remotely sensed data. The objective of this study was to characterize glyphosate efficacy when it was applied with conventional and emerging aerial spray nozzles based on use of ground-based spectral reflectance data.

Material and Methods

Study site

The field used for this study was located in Burleson County, Texas (30.524588°N, 96.407181°W) and was treated with glyphosate on March 2, 2009. The field had been left fallow for the previous eight months and thus, was populated with both broadleaf and grass weeds. Figure 1 is the photo of the study weed field which was taken on Feb 24, 2009. The soil type, ShA, was Ships clay, 0 to 1 percent slopes, rarely flooded. Figure 2 shows the soil map of the study weed field (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey).

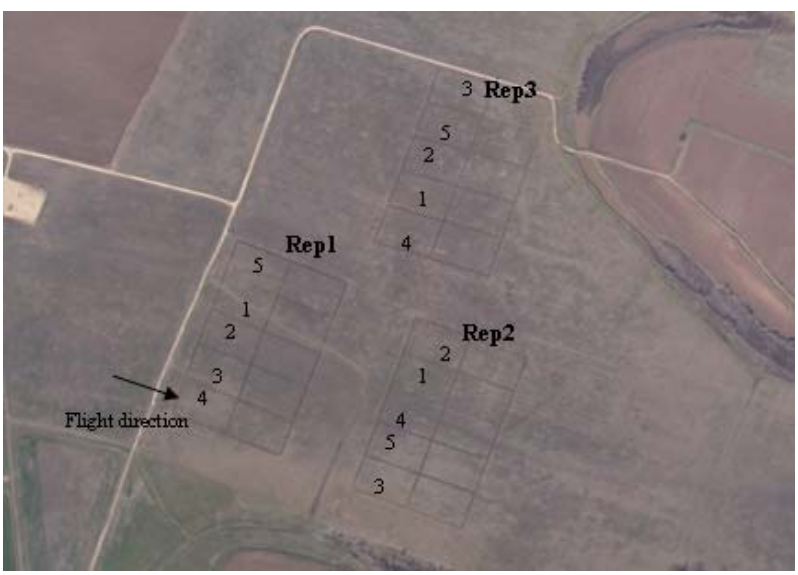


Figure 1. The photo of the study site taken on Feb 24, 2009

Figure 2. Study field soil map, Burleson County, Texas (provided by USDA)

Treatment protocol

Treatments were applied in randomized complete blocks with three replications (Figure 1). Each replicate block was subdivided into five unique randomized treatments. This design strategy improved the accuracy of the comparisons among nozzle technologies by eliminating the variability among the replicates with a block, the order in which the five treatments were tested was randomly determined. Each treatment plot was three aircraft swaths wide (195 ft) and 600 ft long and was delineated with a disked strip of soil (Figure 1 and 3).

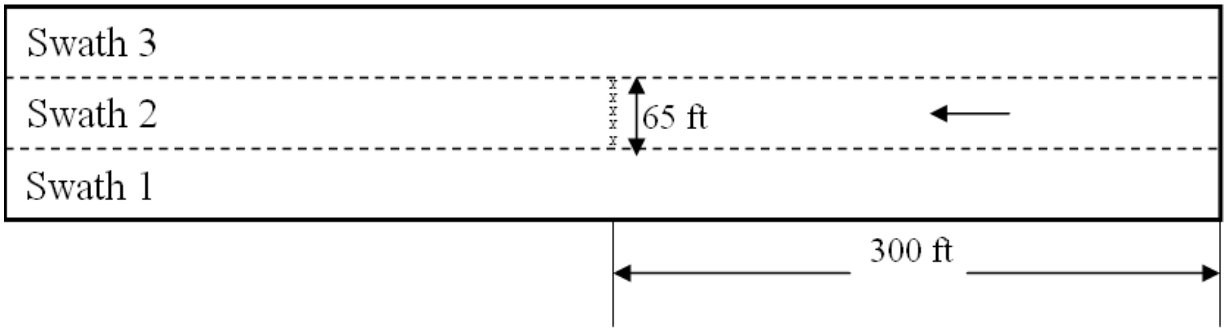


Figure 3**.** Sampling locations layout within each treatment plot

A turbine-powered Air Tractor AT-402B agricultural aircraft (Air Tractor, Inc., Olney, Texas) was used to make all applications. Treatments were made with aerial electrostatic nozzles (Spectrum Electrostatic Sprayers Inc, Houston, TX), CP-11TT 4015 hydraulic flat-fan nozzles (CP Products, Tempe, AZ) and AU-5000 rotary atomizers (Micron Sprayers Ltd., Bromyard, Herefordshire, UK). Table 1 shows aircraft and nozzle settings for each treatment. Droplet $D_{V0.5}$ [Volume Median Diameter (VMD)] is the diameter of droplets such that 50% of the total

volume of droplets is in droplets of smaller diameter. The VMD values were determined using USDA-ARS Spray Quality models (Kirk, 2007) and the nozzle and aircraft operating parameters, including spray pressure, nozzle type and deflection, and airspeed. The aircraft approached the field from the North and flew over the second swath from the North to the South (Figure 3). The spray height was 10 foot.

Table 1. Spray treatment setups and droplet size information

TRT	Nozzle	# Nozzles	Rate (L/ha)	Orifice	Deflection (Degrees)	Pressure (KPa)	Airspeed (KPH)	Target VMD[a]
1	Electrostatic Off	100	9.4	TXVK-8	0	483	209	200
2	Electrostatic On	100	9.4	TXVK-8	0	483	209	200
3	CP-11TT	39	28.1	15	0	241	210	350
4	AU-5000	8	28.1	VRU=Max[b]	Blade-65	241	177	350
5	Untreated Check	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[a] VMD is the volume median diameter which is the diameter of droplet such that 50% of the total volume of droplets is in droplets of smaller diameter. [b] VRU is the Variable Rate Controller for the Micronair AU5000 and is used to adjust flowrate to the nozzle. Max is the full open setting.

All treatments were made with Helosate Plus™ (Helm Agro US, Inc., Memphis, TN) at 1168 mL/ha (16 oz./acre) and 0.5% V/V R-11 non-ionic surfactant (Wilbur-Ellis Co., Fresno, CA). Helosate Plus contains 41% glyphosate (n-(phosphonomethyl) glycine), in the form of its isopropyl amine salt. Each treatment's spray mixture also contained Caracid Brilliant Flavine fluorescent dye at a rate of 37 g/ha (15 g/acre).

Sensing system

A sensing system (Lan et al., 2008) was assembled using Greenseeker® Hand-held Data Collecting and Mapping unit (NTech Industries, Inc., Ukiah, Cal.) and a FieldSpec® (Analytical Spectral Devices, Inc., Boulder, CO) spectroradiometer. The Greenseeker and FieldSpec sensors were mounted on a tractor at a height of 1 m above the ground. Sampling was done as the tractor was driven along the strips which were marked in the center of each treatment plot (Figures 1 and 3). The spectral data collecting in the center swath was used for statistical analysis to avoid the effects of cross contamination between treatments.

As the Greenseeker sensor moved over the field, it measured incident and reflectance light from the target and outputted NDVI readings. Weeds within each plot responded in a similar manner to treatments, so NDVI data of the center swath of each treatment plot were averaged to give a single value for each treatment. The analysis of variance (ANOVA) was carried out based on

the experimental data using Design-Expert® 7.1 software (www.statease.com). Treatment variables were considered fixed and experimental runs were random.

With an angular field-of-view of 25°, the FieldSpec scanned approximately 0.23 m^2 of weed field. The spectroradiometer collected spectral data from the ground ranging from a wavelength of 325 nm to 1050 nm with a sampling interval of 1.4 nm. The spectroradiometer outputted 512 continuous data points with each reading. Ten spectral measurements were taken from each treatment plot. By averaging these ten measurements, a single reflectance measurement was obtained for each treatment plot, thereby, minimizing measurement noise. Instrument optimization and white reference measurements were performed prior to each treatment plot measurements (Castro-Esau et al. 2006). The spectroradiometer was adjusted to 10 scans per dark current and the integration time was set at 217 ms. All the field tests were conducted between 12:00 a.m. and 2:00 p.m. at 1, 8, and 17 days after aerial treatment (DAT).

Results and Discussion

Greenseeker NDVI

The ANOVA test results on DAT 1 and DAT 8 did not show any difference among treatment means. The ANOVA test on DAT 17 is shown in Table 2. Nozzle type had a significant effect on glyphosate efficacy (p = 0.0315 at α = 0.05). The analysis indicated a significant difference in treatment means, so comparisons between paired treatments were conducted using Design-expert to perform a Fisher LSD procedure (Table 3). For α = 0.05, Treatment 2, 3, and 4 were significantly different from Treatment 5. Therefore, electrostatically charged nozzles powered on, CP-11TT flat fan nozzles and AU-5000 rotary atomizers were more efficacious than the electrostatically charged nozzles powered off in controlling weed populations.

Table 2. Analysis of variance test result on DAT 17

Source	Degree of freedom	F-Value	P-value (Prob > F)	
Block	2			
Model	4	4.62	0.0315	significant
A-Treatment	*4*	*4.62*	*0.0315*	
Residual	8			
Cor Total	14			
Std. Dev.	0.036	R-Squared	0.6981	
Mean	0.26	Adj R-Squared	0.5471	

Table 3. Fisher LSD procedure

Treatment	Mean Difference	df	Standard Error	t for H_0 Coeff=0	Prob > |t|
1 vs 2	0.066	1	0.029	2.26	0.0538
1 vs 3	0.083	1	0.029	2.87	0.0209
1 vs 4	0.065	1	0.029	2.24	0.0558
1 vs 5	-0.015	1	0.029	-0.53	0.6137
2 vs 3	0.018	1	0.029	0.61	0.5602
2 vs 4	-6.667E-004	1	0.029	-0.023	0.9823
2 vs 5	-0.081	1	0.029	-2.78	**0.0238**
3 vs 4	-0.018	1	0.029	-0.63	0.5459
3 vs 5	-0.099	1	0.029	-3.39	**0.0095**
4 vs 5	-0.080	1	0.029	-2.76	**0.0246**

The two-way ANOVA test was carried out based on data from all time periods and the result are reported in Table 4. The analysis indicated that both treatment and DAT were significant in the model at α = 0.1 and α = 0.05 level, respectively, while their interaction was not. Figure 4 shows the effects of the two factors on 3D graph. NDVI values in all treated plots were decreased dramatically.

Table 4. Two-factor Analysis of variance test result based on all experimental data

Source	Degree of freedom	F-Value	P-value (Prob > F)	
Block	2			
Model	14	2.87	0.0084	significant
A-Treatment	*4*	*2.53*	*0.0631*	
B-DAT	*2*	*11.26*	*0.0003*	
AB	*8*	*0.95*	*0.4914*	
Residual	28			
Cor Total	44			
Std. Dev.	0.050	R-Squared	0.5897	
Mean	0.30	Adj R-Squared	0.3846	

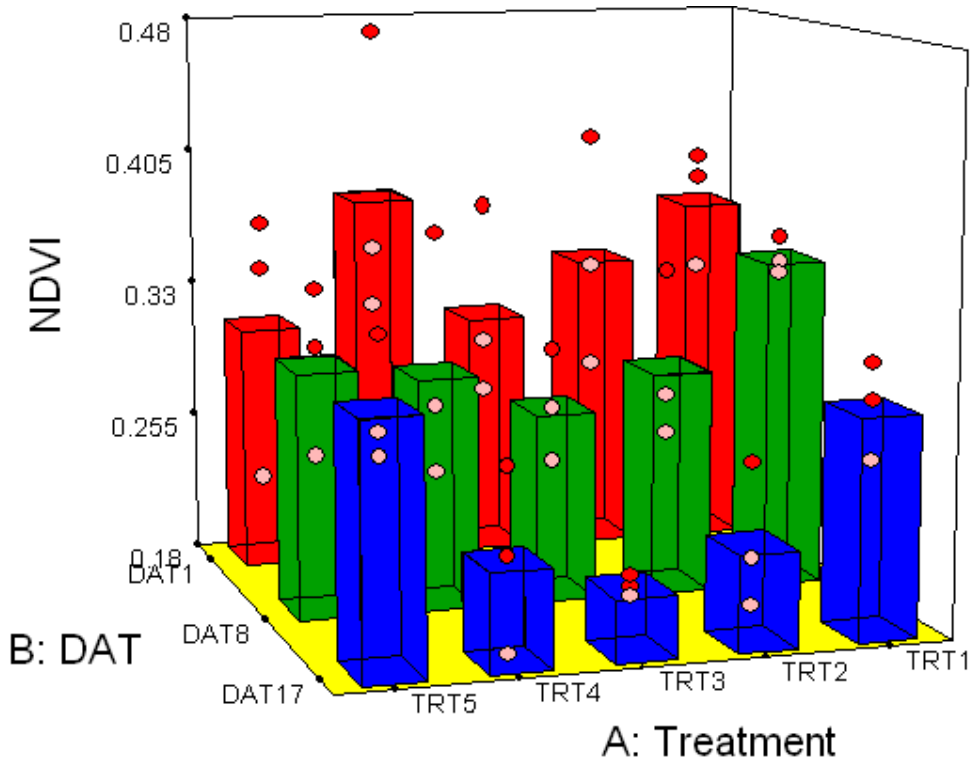
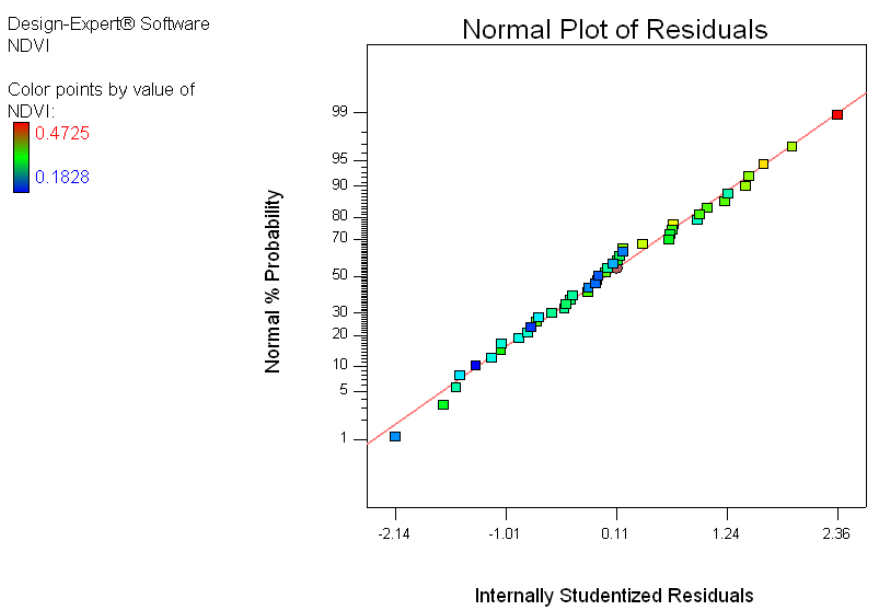


Figure 4. Effects of treatment and DAT on NDVI

The normal plot of residuals and the residuals versus predicted value plot (Figure 5) show that there was no indication of nonnormality, nor was there any evidence pointing to possible outliers.



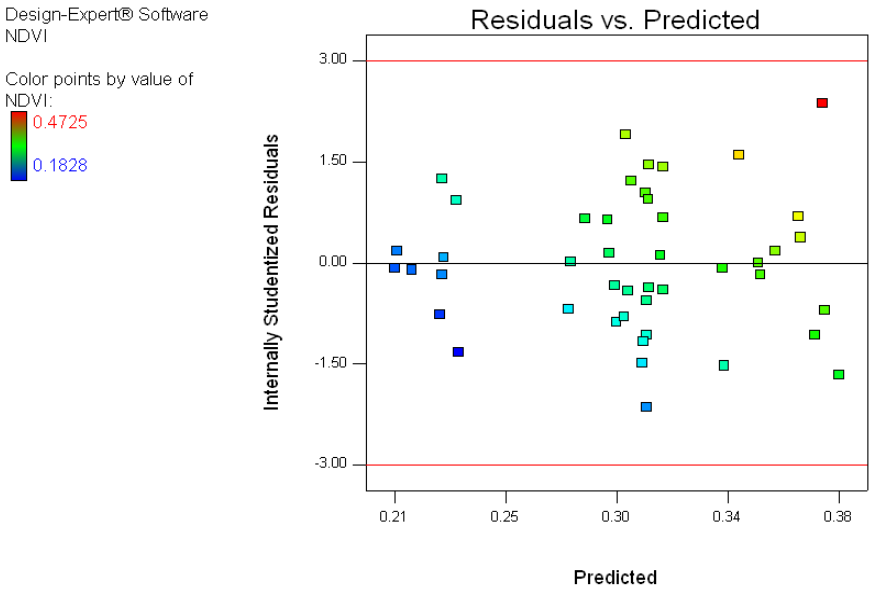


Figure 5. The Normal plot of Residuals and Residuals vs. Predicted value plot for two-way ANOVA test

FieldSpec spectral reflectance

With a spectroradiometer, we can detect a slight reflectance in blue (450 - 480 nm) and red (600 -700 nm), a little more in green (500 - 550 nm) and substantially more in the NIR at 750 -1100 nm for healthy plants.

The average spectral reflectance values obtained by the FieldSpec spectroradiometer for each treatment plot from three replicates at DAT 1, DAT 8 and DAT 17 are shown in Figure 6, 7 and 8, respectively. The overall changes within the study field were observed from the shapes of the reflectance curves. Overall decreases in healthy weed area due to herbicidal control resulted in an increase in the blue and red reflectance and a decrease in the NIR reflectance. Since the soil type of the study field was the same (Figure 2), the effect of soil property was not a factor. As shown in Figure 6, the spectral reflectance responses from five treatment plots were similar at DAT 1. Treatment 3 had higher reflectance both in the visible and NIR wavelength regions at DAT 8 (Figure 7). At 17 days after treatment, there was a significant increase in the visible reflectance under treatment 3 (Figure 8). Compared to DAT 1, the reflectance at DAT 17 increased from about 8% to 20% in the blue region, 15% to 38% in the green region, and 15% to 30% in the red region. Basically, changes to the reflectance in the NIR region were not significant. Treatment 2 and 4 were comparable. Notice that at DAT 17, the untreated check area (TRT5) had the smallest reflectance in the visible region but the largest reflectance in the NIR. It was concluded that the glyphosate herbicide efficacy under different aerial spray treatments could be differentiated based on spectral responses over the visible and NIR spectrum regions.

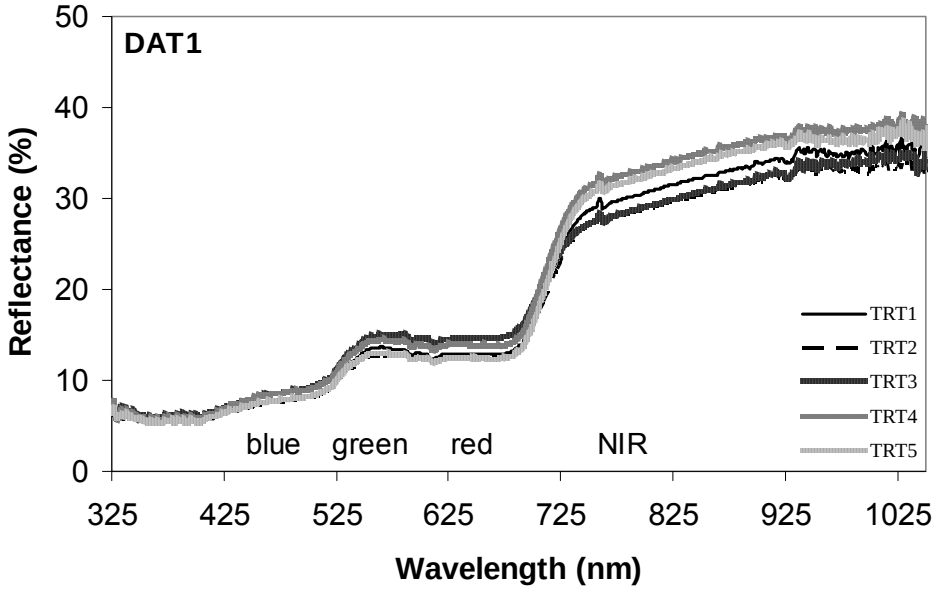


Figure 6. Average spectral reflectance curves for each treatment plot from three replicates at DAT 1

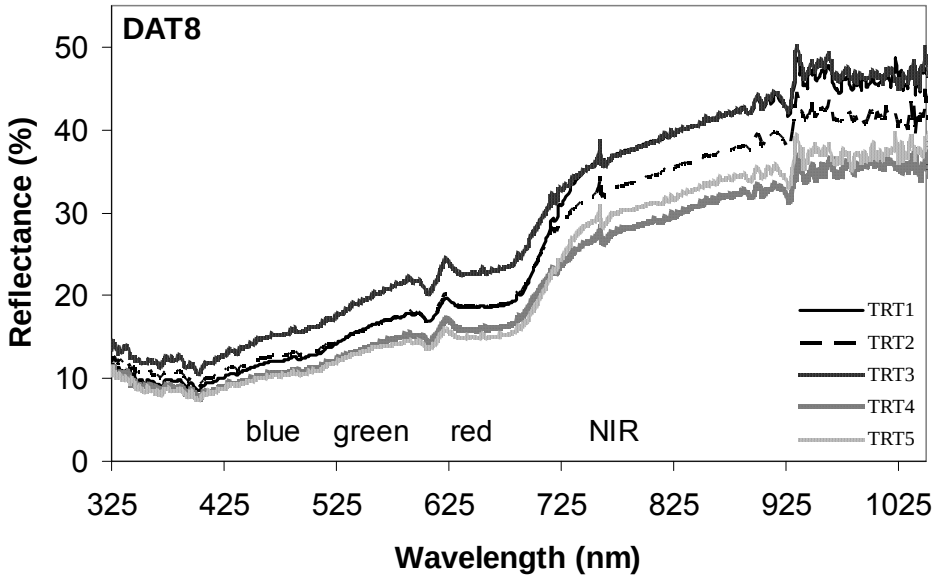


Figure 7. Average spectral reflectance curves for each treatment plot from three replicates at DAT 8

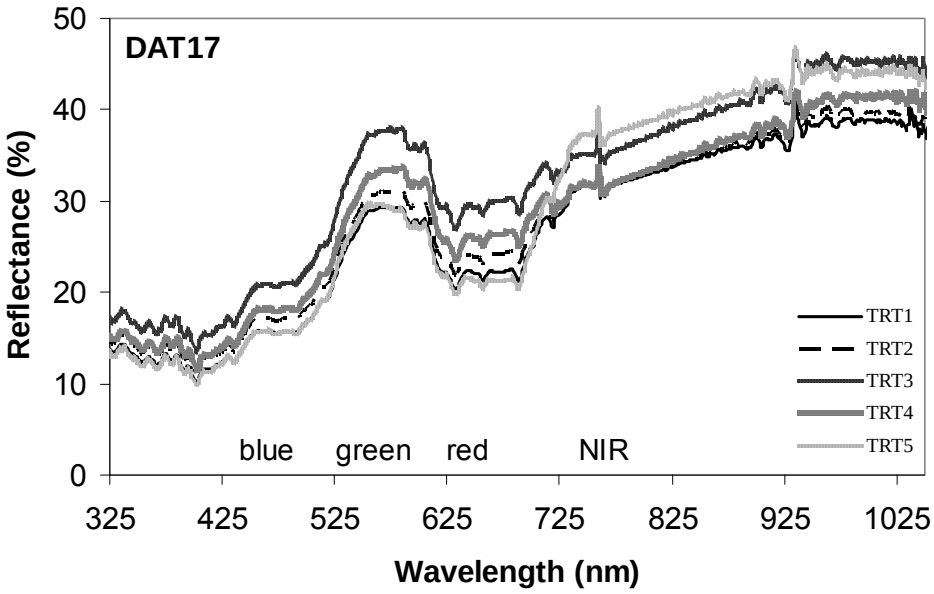


Figure 8. Average spectral reflectance curves for each treatment plot from three replicates at DAT 17

Conclusions

This study was conducted to evaluate glyphosate efficacy on broadleaf and grass weeds applied with conventional and emerging aerial spray nozzles using ground-based spectral reflectance data. The analysis of variance test results of NDVI measurements from the Greenseeker-collected data on DAT 1 and DAT 8 did not show any difference among treatments; however, a significant difference in treatment means on DAT 17 was observed (*p*-value: 0.0315 at $\alpha = 0.05$ level); and electrostaticly charged nozzles powered on, CP-11TT flat fan nozzles and AU-5000 rotary atomizers were more efficacious in controlling weed populations. The two-way ANOVA test over all time periods indicated that both treatment and DAT were significantly affecting mean treatment NDVI values. All glyphosate application treatments provided effective weed control as compared to untreated areas at DAT 17. Based on the analysis of spectral reflectance measurements with the FieldSpec spectroradiometer, the overall changes within the study field were observed from the shapes of the reflectance curves. Glyphosate herbicidal efficacy under different aerial spray treatments could be differentiated from spectral responses over the visible and NIR spectrum regions. At DAT 17, Treatment 3 plot had a highest spectral reflectance in the visible wavelength bands.

Overall, the ground-based spectral reflectance data could be used to assess glyphosate efficacy when applied with different aerial spray technologies. This research showed that reflectance data obtained from either an aerial or ground based platform can be used to compare treatment performance for aerial herbicide application using different nozzle technologies. For this study, aerial herbicide applications performed within labeled recommendations were efficacious, regardless of the nozzle technology employed.

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