MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECTS 47-2014 AND 49-2013
FINAL REPORTS

TITLE: Optimal Timing of Aerial Spray Application to Avoid Inversion-Induced Far-Field Movement of Spray (49-2013)

TITLE: Surface Conditions Affecting the Likelihood of Temperature Inversions and Timing of Aerial Spraying (47-2014).

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EXECUTIVE SUMMARY

Guidelines for pilots that are indicated from this research are:

- Although a slight inversion may still exist, spraying can be allowed when wind speed (at 15 foot height) is 4 mile hr^{-1} or greater. Enough mixing of layers occurs, bringing the Stability Ratio towards neutral.

- The time window during the day, under which spraying is allowed, is shortened early (i.e., Feb-April) and later in the season (i.e., October) due to delays in ground heating.

- On clear summer days, the pilot can begin spraying ½ hour after sunrise and should quit spraying one hour before sunset. On clear days in the Spring and Fall, the pilot can spray one hour after sunrise but should leave the field 1½ hours before sunset. If there is zero wind towards dusk, conditions will change very rapidly towards an inversion. This requires that the pilot leave the field ½ hour earlier than these guidelines dictate.

- If applying over bare soil, the pilot can spray somewhat earlier in the day than if over a full canopy, due to rapid ground heating. By preliminary analysis of data, however, the allowable "head start" for the pilot appears to be relatively short (on the order of 15-30 minutes).

Flow logic based on (and refined from) these results is being used to develop a web-based system for agricultural pilots and farm managers.

This work will benefit aerial applicators and soybean producers alike, and when a web-based system is developed, universal accessibility will be achieved.

BACKGROUND AND OBJECTIVES

It is essential that the aerial applicator avoid application of agricultural pesticides under 'stable' atmospheric conditions when a temperature inversion is likely to occur. Aerial spraying must not occur where a temperature inversion prevents the spray cloud settling within the treated area. When the wind picks up, this stagnant spray cloud has the potential to move far off-target and cause potential damage to both crop and noncrop plants that are downwind.

Guidelines for Mississippi and most other States regarding spray avoidance during temperature inversions are very general and inadequate. It is thus useful and instructive to document the time and duration of stable atmosphere and temperature profiles on a seasonal basis to provide better guidelines for agricultural pilots in Mississippi.

While obtaining data, we have also attempted to validate an Arkansas Plant Board rule that bases decisions of when to spray on easily measured changes in air temperature in the morning and evening. Basing decisions on when to spray on a single temperature reading is very simple for a farm manager or applicator to implement, but it is now clear based on observational data that a wind measurement or 'wind rule' must also be incorporated to give accurate recommendations. A decision support flow chart is being developed for Web access of recommendations based on weather data.

Objectives (49-2013):

1. Obtain data from weather towers and apply the Stability Ratio equation to track atmospheric stability over a cropping season.

2. Translate results into meaningful guidelines that pilots and farm managers in Mississippi can use to avoid spraying under stable atmospheric conditions, and present these recommendations for all weather scenarios likely to be encountered.

Objectives (47-2014):

1. Obtain data from several weather towers and apply the Stability Ratio equation at spatial locations to track atmospheric stability over a cropping season; quantify the effect of dynamic stability governed by mechanical turbulence (wind).

2. Translate results into meaningful guidelines that pilots and farm managers in Mississippi can use to avoid spraying under stable atmospheric conditions and present these recommendations for all weather scenarios and common surface conditions likely to be encountered.

3. Build formal flow logic based on objective 2) that can be programmed into an application for Iphone and Android-based communications devices.

PROGRESS (49-2013)

Objective 1 - *Obtain data from weather towers and apply the Stability Ratio equation to track atmospheric stability over a cropping season.*

All weather data have been obtained from the tall tower to track temporal trends in atmospheric stability. Figures 1-3 illustrate example plots of atmospheric stability as a function of wind for April, July, and September, representing three different periods of the growing season. Numerical criteria for atmospheric stability categories are as follows (Yates et al., 1974). Spraying is permissible under Unstable or Neutral conditions only.

Atmospheric Stability Category	SR Range
Unstable	-1.7 to -0.1
Neutral	-0.1 to 0.1
Stable	0.1 to 1.2
Very Stable	1.2 to 4.9

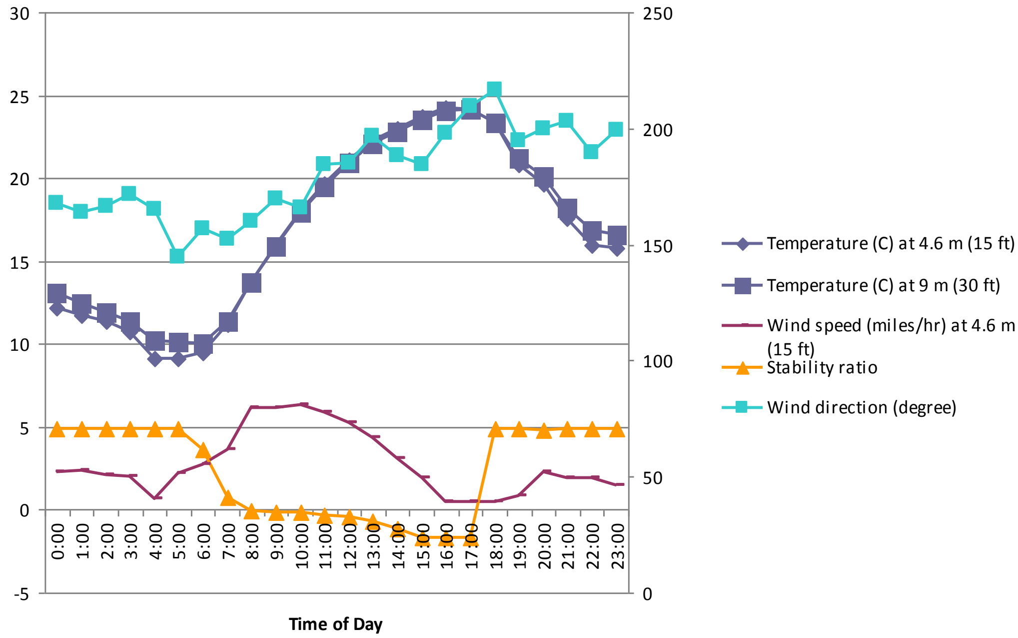

Fig. 1. Stability ratios, temperatures, and wind for 15 April. Left axis scale matches legend variables. Right axis is the scale for wind direction (degrees). 1 mile/hr = 0.447 ms^{-1}

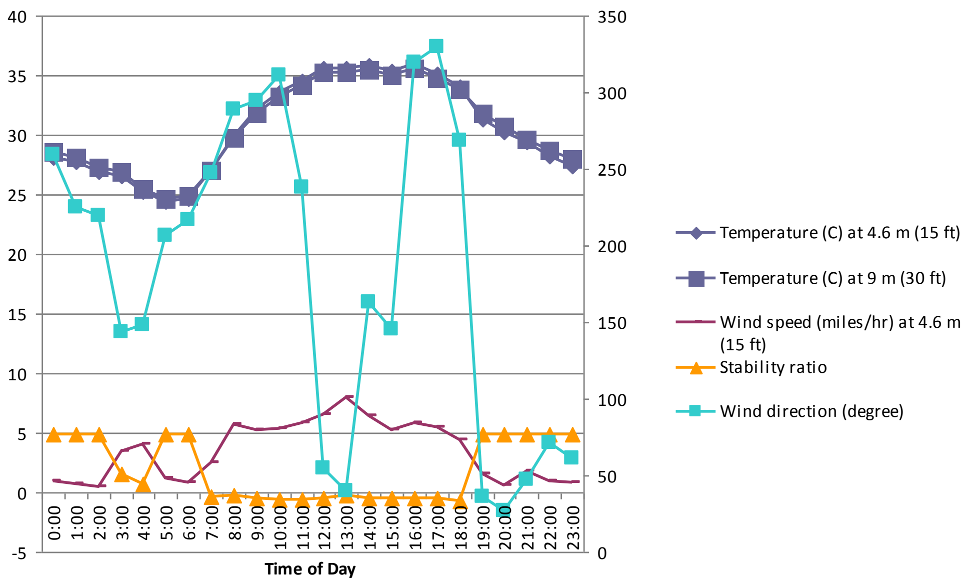

Fig 2. Stability ratios, temperatures, and wind for 15 July. Left axis scale matches legend variables. Right axis is the scale for wind direction (degrees). 1 mile/hr = 0.447 ms^{-1}

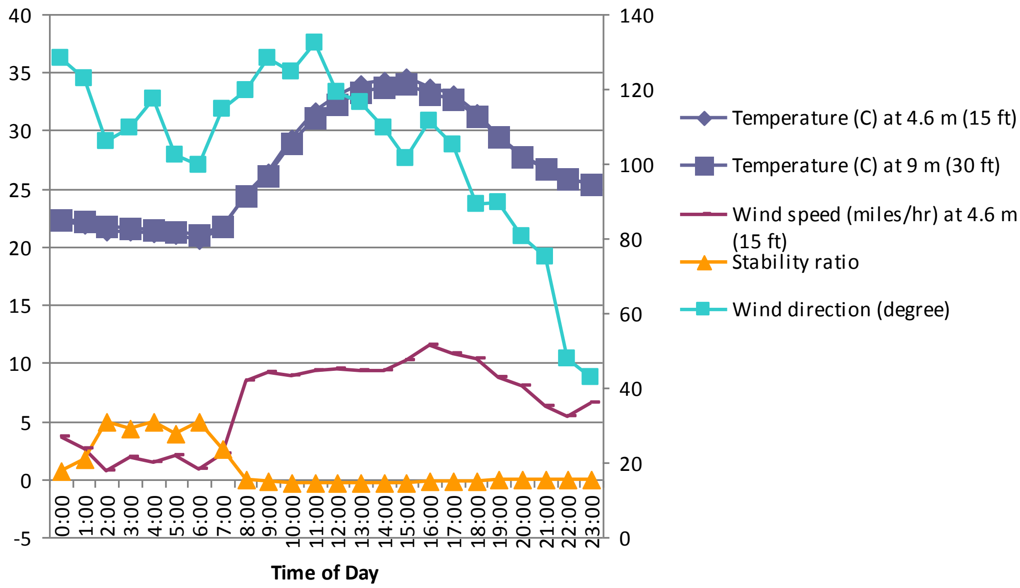

Fig. 3. Stability ratios, temperatures, and wind for 15 September. . Left axis scale matches legend variables. Right axis is the scale for wind direction (degrees). 1 mile hr^{-1} = 0.447 ms^{-1}

Objective 2: *Translate results into meaningful guidelines pilots and farm managers in Mississippi can use to avoid spraying under stable atmospheric conditions and present these recommendations for all weather scenarios likely to be encountered.*

When we began this work, we asked the basic question: Can temperature and wind data obtained from towers be easily incorporated into spraying recommendations for farm managers and aerial applicators? We realized that most farm managers would not erect a tall tower and take precision measurements. However, we surmised that data from these towers could be used to provide general recommendations if environmental conditions closely matched conditions under which data had been obtained.

We also began to develop plans for use of portable towers with remote data acquisition capability that a crop consultant might use. While developing options and realizing problems that Arkansas went through regarding the detrimental effects on cotton of spraying 2, 4-D to soybeans, rice, and pastures (attributed to temperature inversions), we discovered language in the Arkansas State Plant Board (ASPB, 2008) regulations that specifically addresses this issue. The regulation has been modified with varying degrees of specificity but as of 2008 states "*As an indicator that an inversion is unlikely to exist, the applicator shall record the ambient temperature measured at the field of application for each application. Inversions are much less likely to exist if the temperature has increased three (3) degrees Fahrenheit from the morning low at the time of application for applications made before noon or has not decreased more than three (3) degrees Fahrenheit from the afternoon high for applications made after noon*." Being able to base spraying recommendations on a single pair of temperature readings would be extremely convenient.

Table 1 illustrates our attempt at comparing data obtained from towers to criteria presented by the ASPB. The rule written for Arkansas requires a 3º F temperature rise in the morning hours before aerial spraying can occur safely (in neutral or unstable atmosphere). Results indicate that the criteria for unstable or neutral conditions suitable for spraying were satisfied by 0700 on both 15 July and 16 August.

Table 1. Atmospheric stability ratios for five selected dates using air temperatures measured at 15 ft and 30 ft above ground level. Temperature change indicated in **bold** due to change of state can be compared with guidelines for required 3° F temperature difference (increase in morning; decrease at night) to assure neutral or unstable conditions.

Julian Day	Date	Time (24 hr scale)	Time offset from sunrise/sunset (min)	Stability Classification	Stability Ratio	Wind Speed (mile h^{-1})	Air Temperature (F) at 15 ft	Temperature Change (F)	ASPB Criteria met?
106	15-Apr	0600	-33	V-stable	3.67	2.75	49.1	0.72	
		0700	27	**Stable**	0.76	3.67	52.2	**3.78**	No
		0800	87	**Neutral**	-0.08	6.11	56.7	**8.28**	Yes
		1700	-155	Unstable	-1.70	0.51	75.6	-0.09	No
		1800	-95	**V-stable**	4.90	0.51	73.9	**-1.66**	No
197	15-Jul	0600	-5	V-stable	4.90	0.87	76.5	0.59	
		0700	55	**Unstable**	-0.39	2.53	80.6	**4.84**	Yes
		1800	-134	Unstable	-0.40	4.43	93.2	-3.49	Yes
		1900	-74	**V-stable**	4.90	1.50	88.9	**-7.81**	Yes
229	16-Aug	0600	-27	V-stable	4.90	0.51	58.8	0.05	No
		0700	33	**Unstable**	-1.70	0.51	63.0	**4.14**	Yes
		0800	93	Unstable	-1.70	2.73	71.6	12.85	
		1800	-108	Unstable	-0.41	5.06	84.2	-2.92	No
		1900	-48	**Stable**	1.06	3.40	79.3	**-7.81**	Yes
259	15-Sep	0700	13	V-stable	2.66	2.17	70.7	1.49	No
		0800	73	**Neutral**	-0.08	8.41	75.9	**6.32**	Yes
289	15-Oct	0700	-8	Stable	0.63	4.32	46.1	0.79	No
		0800	52	**Neutral**	0.03	4.72	50.2	**4.90**	Yes
		1700	-89	Neutral	-0.05	6.40	71.4	0.92	
		1800	-29	**Stable**	0.99	2.89	67.1	**-4.79**	No

Criteria for neutral or unstable conditions (suitable for spraying) were satisfied between 0700 and 0800 in April, September, and October. This is a significant finding, as aerial spraying for burn-down herbicide applications customarily occur in the late winter and early spring. Pilots need to delay spraying in the morning during the cooler months.

Stable or very stable conditions returned by 1900 in July and August and by 1800 in April and October. The values for September are not shown because higher winds maintained unstable conditions from 1800 to 2300 (Fig. 3). The ASPB rule of stopping spray before a 3º F temperature decrease appeared to be exceeded for all example dates shown in Table 2, except April. However, an unstable condition was still indicated on 15 July when this value was exceeded, indicating that a 3º F reduction might be conservative for hot, dry days. Likewise, the temperature reduction result almost matched a 3º F for 15 August while unstable conditions still prevailed. For July and August, however, the ratio indicating instability was rather weak (-0.40 and -0.41 respectively) at 1800. In April, wind was very calm in the afternoon and atmosphere became very stable rapidly before air temperature measured at 15 ft decreased. The transition from stable to very stable conditions thus indicated high sensitivity to small temperature inversions after 1700. A pilot would need to use extreme caution in the late afternoon under calm conditions, as little or no mixing of atmospheric layers can cause rapid switch from unstable to stable conditions, unfavorable for spraying.

PROGRESS (47-2014)

Objective 1 – *Obtain data from several weather towers and apply the Stability Ratio equation at spatial locations to track atmospheric stability over a cropping season; quantify the effect of dynamic stability governed by mechanical turbulence (wind).*

Portable towers were purchased as a possible do-it-yourself method of taking detailed weather measurements, but we had some issues with leveling and maintaining the wind sensor. Thus, an alternate plan was developed to obtain wind at ground level (described herein), and temperatures from the tower. The Kestrel 4500 weather trackers worked well and Bluetooth communication range for data acquisition was tested to be approximately 55 ft. We obtained preliminary data from a portable tower and noticed a small amount of drift in readings. A procedure was developed to calibrate the Kestrel units against each other.

Figures 1-3 indicate the effect of wind on atmospheric stability. It can be observed from all data that the stability ratio approaches neutral conditions (suitable for spraying) at about 4 mile hr^{-1} (1.79 ms^{-1}) or above. Spraying is thus permissible if wind speed at the 15 ft height remains above this value, regardless of relative temperature readings.

With an eye on practical acquisition of wind data and difficulty in reliably acquiring wind speed using portable towers, we wanted to determine if wind speed could be extrapolated upwards from ground level to 15 ft (or 4.6 m), the required height for use of the stability equation. A mathematical log model was tested for accuracy in producing estimates of wind speed at 15 ft, if wind data were obtained from a different height. The equation used to interpolate that value is presented by Cooper and Alley (1994) as a logarithmic interpolation. We will use SI units for this illustration.

$$\frac{u_2}{u_1} = \left(\frac{z_2}{z_1}\right)^p$$

where

z_1, z_2 = elevations 1 and 2 (m)
u_1, u_2 = wind speeds at z_1 and z_2, m s^{-1}
p = exponent, unitless

Herein we use example data from College Station TX and Stoneville MS to test the equation. An initial reason for evaluating this function was that wind speed for an inversion experiment at College Station was measured at a different height (albeit not at ground level) than that required by the stability equation. There appeared to be a slight discrepancy between wind speeds indicating stable atmosphere from the College Station and Stoneville locations, so we wanted to see if the differences were caused by inaccurate characterization of wind speed.

At the Stoneville location, preliminary data had shown that wind speeds measured at the 15 foot height in the morning typically ranged from 2.8 to 3.6 mile hr^{-1} during the transition from stable to unstable conditions (the former being unfavorable conditions for spraying). The College Station study indicated a higher wind speed (4.47 miles hr^{-1} or 2.0 ms^{-1}), but this value had been interpolated to 15 m based on wind speeds measured at non-standard 2.5 and 10 m heights.

To determine relative accuracy of this equation, data from the weather tower obtained at two heights and the interpolation equation were used to find wind speed at the intermediate height for comparison with measured values. An example set of readings and calculations for two pairs are illustrated in Table 2. For each pair, the exponent p was determined and then used to calculate the wind speed at intermediate heights using wind speed at both the lower height (z_1) and the higher height (z_2). Results illustrate that results differed depending on which height was used in the log interpolation equation, but in no case did the interpolated value exceed the measured value by more than 6.3%. This indicates that the interpolated wind speed below which stable conditions unfavorable for spraying occurred at College Station TX (4.47 mile hr^{-1}) was probably not too high an estimate for that location, indicating suitability of the log model if applied properly. Our new data confirm a 4 mile hr^{-1} threshold above which spraying is safe, which is close to the College Station value.

Table 2. Wind speeds interpolated from tower data using log function. Calculated values are in **bold**.

u_1 (m s^{-1})	1.2	2.0
u_2 (m s^{-1})	2.5	3.4
Ratio of u	2.1	1.7
z_1	4.6	12.2
z_2	19.8	27.4
Ratio of z	4.33	2.25
p	0.50	0.62
Interpolation of wind speed at intermediate height		
Desired height from which to obtain wind speed (m)	12.2	19.8
Actual (target) wind speed (m s^{-1})	2.02	2.56
Interpolated wind speed using wind speed at z_1	**1.57**	**2.47**
Interpolated wind speed using wind speed at z_2	**2.01**	**2.73**
% difference from actual wind speed (using z_1)	28.7	3.5
% difference from actual wind speed (using z_2)	0.5	-6.3

While conducting the study and getting a feel for "safe spraying" time intervals, the PI noticed that many pilots were spraying close to the threshold times for safe spraying. He decided to log these times and, using weather data from our towers in concert with historical data from Weather Underground, created tables for evaluation against ASPB (2008) rules regarding morning and evening temperature difference. One such table is illustrated in Table 3. We observed two out of eleven runs (18%) where the pilot likely sprayed outside the permissible time window. In one case, the pilot went out too early; in another he stayed out too late.

The case of June 12, 2012 showed a one degree temperature rise (minimum 3 degrees needed per ASPB guidelines), but average wind speed was just under the 4 mile hr^{-1} threshold of acceptability. The afternoon run of March 1, 2012 was clearly not acceptable for spraying. There was already a 5 degree decrease in air temperature and conditions were dead calm.

Table 3. Observational data of pilot flights from 2012.

Date	Time weather data acquired (24 hr scale)	Time of flight (24 hr scale)	Actual T (F)	Min T (F)	Max T (F)	Wind Speed at 15 ft (mile hr^{-1})	AR Temp Criteria Satisfied?	**Safe to Spray?**
02-21-12	0653	0700	44	43	-	6.76	No	Yes
03-01-12	1753	1800	73	-	78	0.00	No	**No**
03-04-12	0653	0700	39	34		3.38	Yes	Yes
03-07-12	1753	1800	72	-	76	8.46	Yes	Yes
03-10-12	0653	0700	41	40	-	4.27	No	Yes
03-28-12	0653	0700	63	60	-	3.38	Yes (cloudy)	Yes
06-07-12	0653	0645	64	62	-	4.27	No	Yes
06-09-12	0653	0640	71	68	-	0.00	Yes	Yes
06-10-12	0653	0700	72	71	-	3.38	No (cloudy)	**No**
06-15-12	0653	0700	70	66	-	0.0-2.6	Yes	Yes
06-27-12	1753	1800	91	-	96	3.39	Yes	Yes

Objective 2 – *Translate results into meaningful guidelines pilots and farm managers in Mississippi can use to avoid spraying under stable atmospheric conditions and present these recommendations for all weather scenarios and common surface conditions likely to be encountered*.

Some guidelines for pilots have been indicated thus far, based on research data and observation:

- Although a slight inversion may still exist, spraying can be allowed when wind speed (at 15 foot height) is 4 mile hr^{-1} or greater. Enough mixing of layers occurs, bringing the Stability Ratio towards neutral.

- The time window during the day, under which spraying is allowed, is shortened early (ie. Feb-April) and later in the season (ie. October) due to delays in ground heating.

- On clear summer days, the pilot can begin spraying ½ hour after sunrise and should quit spraying one hour before sunset. On clear days in the Spring and Fall, the pilot can spray one hour after sunrise but should leave the field 1 ½ hours before sunset. If there is zero wind towards dusk, conditions will change very rapidly towards an inversion. This requires that the pilot leave the field ½ hour earlier than these guidelines dictate.

- If applying over bare soil, the pilot can spray somewhat earlier in the day than if over a full canopy, due to rapid ground heating. By preliminary analysis of data, however, the allowable “head start” for the pilot appears to be relatively short (on the order of 15-30 minutes).

Objective 3 – *Build formal flow logic based on objective 2) that can be programmed into an application for Iphone and Android-based communications devices.* Flow logic based on (and refined from) that indicated for Objective 2 is being developed by Thomson and Fisher for this portion of the work. We have changed our initial goal to that of developing a web-based system based on flow logic. We will use Bluetooth communication for acquisition of much of the data required, but enlist other methods compatible for web-based data acquisition. This topic is covered in a newly funded MSPB grant "Web-based interface for atmospheric stability and spray timing recommendations. "

IMPACTS AND BENEFITS TO MISSISSIPPI SOYBEAN PRODUCERS

With our extensive data set, we have been able to quantify when aerial applicators should avoid spraying under certain weather conditions to mitigate the effects of far-field spray drift. Aerial applicators have expressed concern that they are sometimes pressured to spray very early in the morning. There is also a perception that optimal time for spraying is when the wind is calm. This is not the case and our data used with the simplified atmospheric stability relationships have proven this.

This work will benefit aerial applicators and soybean producers alike, and when a web-based system is developed, universal accessibility will be achieved. Thus far, this work has been promoted and presented to aerial applicators. It has become clear, however, that more producers need to see results from our study as they are the ones making field decisions.

END PRODUCTS

Presentation entitled "Portable tower systems and guidelines indicating atmospheric stability" (Thomson, Fritz, Huang, Fletcher) was made at the 2013 meeting of the National Agricultural Aviation Assn. (NAAA), held in December 2013. Dr. Bradley Fritz presented this work.

Invited presentation entitled "Inversion Avoidance" was made at meeting of the Mississippi Agricultural Aviation Assn. (MAAA) held in January 2014.

Presentation entitled "Simple methods for do-it-yourself monitoring of atmospheric stability" (Thomson, Fisher, Huang, Fritz, Fletcher) was made at the 2014 meeting of the National Agricultural Aviation Assn. (NAAA) held in December 2014.

Journal article entitled "Atmospheric Stability Intervals Influencing the Potential for Off-Target Movement of Spray in Aerial Application." In Press for Journal of Agricultural Science.

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