PROJECT PLAN
NP 305 – Crop Production

Old ARS Research Project Number
6202-22000-023-00D

Research Management Unit
Areawide Pest Management

Location
College Station, Texas

Title
Aerial Application Research for Efficient Crop Production

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Planned Duration
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Project Summary

Aerial application of crop production and protection materials is a crucial component of high-productivity American agriculture. This project is focused on optimizing efficacy and minimizing off-target movement of these materials. Project objectives will be accomplished through focus on three main research areas: 1) improving existing aerial application technologies to maximize application efficiency and biological efficacy with minimal spray drift; 2) integration of remote sensing and variable rate systems to enhance and optimize applications of crop production and protection products; and 3) developing decision support systems that provide application equipment selection and operational guidance for optimum biological efficacy. This project combines engineering and entomological expertise to create a research program that defines how sprayed materials move from the aircraft to the target and how efficacy of the applied product is affected and can be optimized by changing deposition characteristics. Results of project research are intended to provide aerial applicators, crop management consultants, extension agents, and agricultural producers with the appropriate scientific knowledge to make the best treatments possible and to be in full compliance with all State and Federal regulations related to the application of agricultural materials.

Objectives

The long-term goal of this project is to develop and implement new and improved aerial application technologies for safe, efficient, and sustainable crop production and protection. The technical expertise within this project contributes to both immediate and long-term sustainability of the aerial application industry in the United States. Over the next five years, we will focus on three main objectives:

Objective 1: Improve existing aerial application technologies to maximize efficiency and biological efficacy of crop production and protection compounds with minimal spray drift and impact to non-target systems.

- **Sub-objective 1.A:** Develop and implement standard procedures for evaluating drift reduction technologies (DRTs) and assessing biological impacts of sprays in crop canopies.
- **Sub-objective 1.B:** Develop and optimize the use of autonomous unmanned aerial vehicles (UAVs) for pest control.
- **Sub-objective 1.C:** Assess biological impacts of spray drift.

Objective 2: Develop remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops.

- **Sub-objective 2.A:** Characterize spatial variability of crop conditions using multispectral imaging to develop treatment maps for use with site-specific aerial application systems.
- **Sub-objective 2.B:** Integrate remote sensing and variable rate aerial application technologies to optimize crop management strategies.
- **Sub-objective 2.C:** Develop sensors that rapidly and/or remotely detect pest presence, crop condition, spray droplets, and volatile organic compounds.
- **Sub-objective 2.D:** Adapt autonomous unmanned aerial vehicles (UAVs) for remote sensing of crop conditions.

Objective 3: Develop, enhance, and implement decision support systems that improve user ability to select and operate application equipment and schedule spray treatments that optimize biological efficacy.

- **Sub-objective 3.A:** Correlate aerial spray dispersion model estimates with off-target biological effects and in-swath deposition.
- **Sub-objective 3.B:** Develop and implement crop growth and management decision systems to optimize aerial applications.

Objectives 1 and 2 are relatively independent, with the majority of a given SY's efforts being dedicated to specific objectives. The results achieved under Objectives 1 and 2 will be incorporated into decision support systems, with each SY contributing his expertise to the achievement of Objective 3 as indicated in Figure 1 and as explained in the Approach and Research Procedures section.

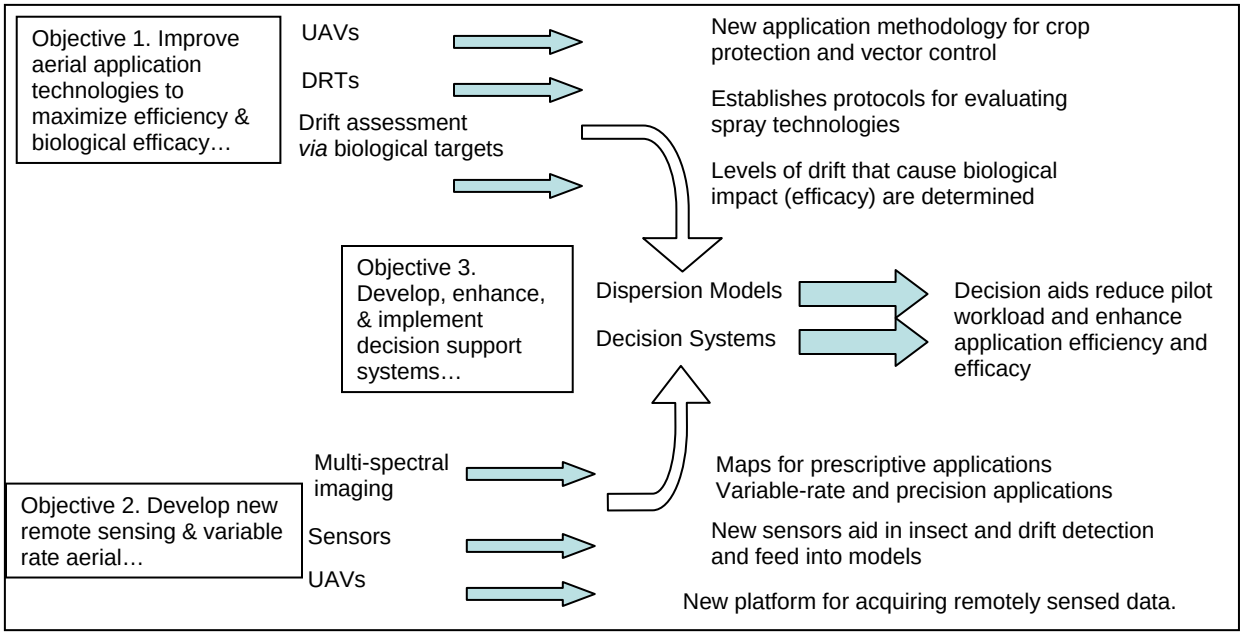

Figure 1. Graphical representation of research objectives and expected outcomes.

Need for Research

Description of the Problem to be Solved: During ARS planning workshops for crop production and protection, the user community for NP305 and NP304 identified application technology as a program area needing significant effort. This project addresses these needs and serves as the primary research resource for the aerial application industry encompassing more than 3,300 applicators. As new chemistries and biological controls are introduced into agricultural systems, these materials or agents must be applied in specific ways to maximize benefits and minimize deleterious effects. Applicators, consultants, and producers must understand how to effectively use these materials, which are crucial to the success and implementation of current and future pest management strategies. The use of remotely sensed data, *via* aircraft or satellite images, coupled with variable rate applications systems, is expected to play an increasingly important role in modern agricultural production. A user-friendly image acquisition and analysis system is needed for aerial applicators to produce their own prescription maps or for new revenue-generating services for their customers. An automated, airborne multispectral imaging system needs to be developed to quantify the stages of crop growth, to identify pest stress over the crop fields, and eventually to provide data to produce prescription maps to direct site-specific application of crop production and protection materials. This project will develop and implement new and improved aerial application technologies for safe, efficient, and sustainable crop production and protection.

Relevance to ARS National Program Action Plan: The research program contributes to the ARS Strategic Plan for 2006-2011, Objective 2.2: Increase the Efficiency of Domestic Agriculture Production and Marketing Systems. As part of the NP 305 Action Plan, this project contributes to Subcomponent 1A: Annual Cropping Systems (Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest Management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System; Problem Statement 1A.3: Decision Support Systems to Optimize Pest Management; and Problem Statement 1A.4: Develop Crop

Production Systems that are Productive, Profitable, and Environmentally Acceptable); and Subcomponent 1B: Perennial Cropping Systems (Problem Statement 1B.2: Develop Mechanization and Automation Practices that Increase Production Efficacy). This project also directly supports Component V (Pest Control Technologies) and Component VI (Integrated Pest Management Systems and Areawide Suppression) of NP304: Crop Protection and Quarantine.

Potential Benefits Expected from Attaining Objectives: Attainment of the stated objectives will benefit aerial applicators, crop consultants, extension agents, farmers, agrochemical companies, scientists, and the public as a whole by making the most judicious and effective use of current application methods, equipment, and crop production and protection materials. The development of new equipment, products, and technology will minimize off-target movement of these applied materials. New crop and pest management technologies developed by this project will significantly reduce the use of some of the most toxic pesticides used in American crop production systems.

Anticipated products of the research:

- Spray drift reduction methodologies for evaluating drift reducing technologies.
- Coupling of aerial remote sensing data and variable rate systems for aerial application.
- Sensors for monitoring pest damage or presence, and crop conditions.
- New spray atomization models to aid users in the appropriate selection and setup of spray nozzles based on the user's specific operational parameters.
- Agricultural aircraft remote sensing systems for detecting crop diseases, nutritional deficiencies, and/or pest damage.
- Increased efficacy of crop production and protection materials, thereby reducing the chance of development of pest resistance.
- Models that relate spray dispersion estimates to biological efficacy.
- Unmanned aerial vehicles (UAVs) for aerial applications, such as in minor and specialty crop production systems.
- A UAV platform for timely and inexpensive acquisition of remotely sensed data.
- Decision support systems integrating crop, geographical, and application systems information to support and optimize aerial applications of crop protection and production materials.

Customers of the research and their involvement: There are more than 3,300 licensed aerial applicators across the United States. These applicators are generally self-employed, single-aircraft business owners. This research project is designed to support the aerial application industry by working with individual applicators and the National Agricultural Aviation Association to address topics vital to the industry. The research projects are designed to make aerial application more efficient and safer, and to assure ongoing economic viability of the industry. In the past, the project has conducted directed research that has benefited cotton farmers, foresters in the Northwest, corn growers with corn rootworm infestations, mosquito control applicators in Florida and the U.S. military, wheat growers, and many others. The atomization models created by the project are used by the U. S. Environmental Protection Agency (EPA), Spray Drift Task Force, U.S. Forest Service, aerial applicators, and the agrochemical industry. Scientists in this project are working with the EPA to address needs and concerns facing the aerial application industry, such as droplet classification, buffer zones, and drift reducing technologies.

Input from customers has been and will continue to be obtained from technical and general conferences, research planning meetings, field days, and discussions between ARS personnel

and our customers. Other ARS locations involved in application research, industry groups, and university personnel will be regularly consulted *via* research planning and technical committee meetings to coordinate research activities. As the landscape and emphasis of American agriculture adapts to reflect changes in the nation's priorities, our project will target a number of additional areas of research that are not necessarily specifically mentioned in this project plan, but that are certainly relevant. We continually look for opportunities, either through variable or reduced rate applications, that can provide applicators with energy savings. We also will seek opportunities where aerial application technologies and techniques can positively impact biofuel production. Our group continues to actively seek and explore new opportunities and avenues where aerial applicators can apply their skills and expertise.

Scientific Background

The main areas of interest to this project are spray drift, biological efficacy of crop production and protection materials, sensor and controls development, remote sensing, variable rate spray applications, and modeling. The use of UAVs in American agriculture production is a relatively new topic that will be part of this Project Plan. This project will build on the prior scientific knowledge discussed in this section.

Spray drift has always been one of the major concerns in the application industry. Spray drift is defined by the EPA as:

> "Spray or dust drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site. Spray drift shall not include movement of pesticides to non- or off-target sites caused by erosion, migration, volatility, or windblown soil particles that occurs after application or application of fumigants unless specifically addressed on the product label with respect to drift control requirements (EPA, 2001)."

Spray drift research typically focuses on the amount and the consequences of spray drift and/or application technologies and methodologies to minimize drift. There is a large body of literature, spanning several decades, that addresses the issue of the degree of aerial and ground spray drift occurring as a result of application, meteorological, and target parameters. Less numerous are studies detailing the biological effects of this drift. The majority of these biological studies use a handheld or ground-based spray system to apply a spray product at levels that simulate those resulting from spray drift. These studies contain a variety of crops and other biota that include, but are not limited to, wheat (Roider, 2006), sugarcane (Richard, 1991), alfalfa (Al-Khatib et al., 1992), and soybeans (Bailey and Kapusta, 1993), **maize (Donald, 1998), native plants (Marrs et al., 1989),** insects such as bees (Pankiw and Jay, 1992) and butterflies (Longley and Sotherton, 1997), **as well as, aquatic organisms in ditches (Arts et al., 2006).** Deposition rates reported in these studies varied from 0.1 to 50% of labeled product application rate, and biological assessments ranged from visual damage to yield assessments for crops, and mortality for insects. The varied results from these studies support previous findings that the effect from a given product at a given dosage is product- and species-dependent (Hewitt et al., 2000). There are a couple of notable aerial application studies that integrated biological samples into the downwind sampling scheme. Ray et al. (1999) used tomato plants alongside fallout plates to determine biological effects of glyphosate spray drift out to 80 m resulting from a helicopter application. Marrs et al. (1992) used common sorrel alongside water-sensitive cards to measure the biological response to spray drift from a helicopter application out to 240 m. The major shortcoming of these studies is the lack of depositional characteristics; i.e., target

coverage and droplet size data, as these data may be critical to the biological impacts seen off-target.

Sayles et al. (2004) proposed the development of a testing program for measuring drift reduction technologies (DRTs) that was recognized by the EPA. Kosusko et al. (2006) provided further framework on how the DRT evaluation program may be conducted. The DRT Program is an EPA-led initiative program to "achieve improved environmental and human health protection through drift reduction by accelerating the acceptance and use of improved and cost-effective application technologies (EPA, 2006)." The first step in implementing the DRT program is to develop a set of protocols, standard operating procedures, and data quality assurance steps so that the results from any trials or research conducted are scientifically valid and repeatable; data quality and protection must also be maintained throughout the study (EPA, 2002). The EPA has asked the USDA-ARS, through this Aerial Application Project, to serve as the initial implementer of the DRT program by developing the necessary protocols and conducting DRT evaluations. In developing and implementing DRT studies over the next five years, project scientists will rely on both established Professional Standards, such as ASABE S572 (1999): Spray Nozzle Classification by Droplet Spectra (wind tunnel work), ASABE S561.1 (2004): Procedure for Measuring Drift Deposits from Ground, Orchard and Aerial Sprayers (field trials), and peer- and EPA-reviewed protocols developed by project scientists.

Remote sensing is a rapid, effective technology for acquiring spatial information that can be used with global positioning system/geographic imaging system (GPS/GIS) systems for implementing crop production and pest management tactics (Pinter et al., 2003, **Willers et al. 2005; Brown and Noble 2005; Board et al. 2007; Du et al. 2008; Lemaire et al. 2008)**. Research with respect to the use of remote sensing for the assessment of crop conditions is readily available in the literature. Airborne remote sensing offers a flexible, highly accurate, and cost-effective approach to acquisition, processing, and analysis of field crop conditions (Hickman et al., 1991; Medlin et al., 2000; Ye et al., 2007). An airborne multispectral imaging system that automates the operation of the camera with position stability has been prototyped to accurately and timely characterize spatial variability of crop conditions (crop growth, pest issues, etc.) to provide spatial treatment data for use in site-specific aerial application systems (Huang et al., 2008; Lan et al., 2007b). Agricultural researchers have successfully used remote sensing to show variability of field or crop characteristics such as fertility, soil type, salinity, water stress, insect pressure, nitrogen levels and biomass (Bronson et al., 2003; Jackson and Ezra, 1985; Pierce and Warncke, 2000; Raun et al., 2002; Sudduth et al., 2001; Temple, 2007). In a multitude of studies, these remotely sensed data have been used to generate prescription maps for ground application of variable rates of inputs to cropland on a site-specific basis. Variable-rate ground applications of fertilizer, lime, herbicides, plant growth regulators, and defoliants have proven successful in reducing costs for farm inputs without adversely impacting yields (McKinion et al., 2001; Miller, 2004).

Variable-rate aerial application introduces a number of opportunities and challenges to the aerial application industry. While variable-rate applications have been a viable option for ground applicators for many years (Monson and Bauer, 1992; Tian et al., 1999), variable-rate aerial applications are relatively new. Applications by ground are typically made at 8-15 mph, while modern agricultural aircraft commonly operate in excess of 130 mph (200 ft/sec). Response time of the application system becomes critical. Several navigation companies have variable rate aerial application systems on the market, but no scientific data has been published to attest to the performance characteristics and abilities of these systems. Thomson (2006) determined that necessary flowrates up to 6.0 gallons per acre (gpa) could be achieved in a fraction of a second using a hydraulic pump and flow controller in an aerial spraying system. Since the

aircraft was moving at approximately 61 m/sec (200 ft/sec), turning the spray on and off at a specific point in the field involved factoring the response of all the components in the spray system and predicting where the aircraft would be at the end of the response time. The best accuracy they were able to achieve was 5 m (16 ft). This study used conventional hydraulic nozzles, which do not maintain a consistent droplet spectrum over the range of pressures necessary to achieve desired application rates. In addition, this study investigated the possibility of generating prescription maps “on-the-fly” but was unsuccessful and the authors conceded that desktop software would still be needed to post-process the images. Thomson (2006) is the only published study evaluating aerial application variable rates systems and highlighting the need for further research and product development in this area.

Current techniques for scouting and monitoring crop pest insects are time-consuming and unreliable unless highly replicated. Volatile chemicals are released by crop plants as part of a defensive mechanism against pests, or as a by-product of chemical reactions in fruiting structures damaged by sucking bugs (Khalilian et al., 2006). Stink bugs and many other crop pests release volatile aggregation or sex pheromones after or while feeding on crop plants. These chemicals are molecularly specific and potentially detectable as a characteristic of insect presence and/or fruit damage in crops. The electronic nose technique has been accepted as an effective tool to detect volatile chemicals **(Stinson et al., 2005) and food borne pathogens (Gardner et al., 2000, Dutta et al., 2002).** Commercially available portable electronic nose detectors are difficult to customize for specific applications (Rains et al., 2004). Further, there is no published information on the development of a customized electronic nose system for detecting the presence of stink bugs or other pests and their associated plant damage; therefore, this Project will work to fill this scientific gap.

Information about crop physiology is increasingly being incorporated into modern farming operations. For time-efficient, non-destructive, and labor-saving measurements, sensors are needed that can determine and predict, preferably on-line, crop physiology. Determination of spatially variable crop conditions is important for optimizing inputs of agrochemicals and improving crop management (Ehlert and Dammer, 2006). Linking multiple sensors in order to make a more accurate estimate of the environment through measurement and detection is an emerging technology. Multisensor data fusion is a technique by which data from a number of sensors are combined through a centralized data processor or neural network to provide comprehensive and accurate information (Huang et al., 2007). This technique will be used by Project scientists in several of the Objectives.

The ultimate tool in any applicator’s toolbox would be the ability to predict spray deposition on the targeted pest or plant, application efficacy, and the degree of and possible impact resulting from off-target spray drift. A couple of software programs, AGDISP and AgDRIFT, have been developed and validated for the purpose of predicting the physical deposition and drift of aerially applied sprays. The development, improvement, and validation of these programs are well documented (Bilanin et al., 1989; Teske et al., 1993; Richardson et al., 1995; Teske et al., 2000; Teske et al., 2003). AGDISP is the model that is currently being used in the field of aerial application (Bilanin et al., 1989, Teske et al., 2003). AGDISP is a near-wake model that “solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on an aircraft” (Teske and Thistle, 1999). Teske et al. (2000) used this model to predict deposition and drift from aerial spray nozzles. Previous studies in two crop canopies have shown that while the levels of spray material that moves downwind may be similar for field-collected data and AGDISP-predicted data, the AGDISP model is very sensitive to certain model inputs (Hoffmann, 2006). Canopy height and wind speed were reported to have significant impact on the amount of material that was predicted to move downwind by the

model. The comparison of field-collected data to the model prediction can improve the confidence that aerial applicators, researchers, and regulators have in the model.

There is one notable model that incorporates biological response into the modeled spray movement predictions: SpraySafe Manager (Richardson et al., 1996; Ray et al., 1999; Schou et al., 2001). The SpraySafe Manager software interfaces with AGDISP and a number of herbicide-plant dose-response curves to predict on-target efficacy and required buffer-zones to prevent any off-target damage during aerial applications of herbicide over forest canopies. SpraySafe Manager does not include any biological response data for on-target efficacy of plant production materials (e.g., plant growth regulators, hormones, or defoliants) or biological response from pesticide applications in general.

Crop models simulate the growth of crops, and provide relevant information for routine crop management (Lan et al., 2006). The use of crop models on large areas for diagnosing crop growth conditions or predicting crop production is hampered by the lack of sufficient spatial information for model inputs. Integrating crop models with other information technologies such as GIS, Variable Rate Techonolgy (VRT), remote sensing, and GPS could further optimize site-specific farming practices to address crop production and environmental issues (Launay and Guerif, 2005; Lan et al., 2007a). By combining spray application models (Bilanin et al., 1989; Richardson et al., 1996; Schou et al., 2001), crop/plant models, and risk management tools, project scientists will maximize the effectiveness of plant protection products and minimize risk to public health and the environment.

Typically, aerial images have been obtained by satellites or piloted aerial platforms, either fixed-wing or rotary-wing (helicopter). More recently, technological advances in UAVs and photogrammetry have permitted increased use of UAVs for remote sensing. Completion of the Defense Department's system of satellites for GPS navigation has revolutionized the precision of UAV guidance systems, and reductions in cost for both the guidance system and digital cameras have made the units more affordable since they are currently to costly for widespread usage. UAVs have been, and continue to be, used extensively in military and civilian applications (Blyenburgh, 1999). Some example applications include archaeological prospecting (Eisenbeiss, 2004), rangeland management (Hardin and Jackson, 2005), assessment of grain crop attributes (Jensen et al., 2003; Hunt et al., 2005a), and vineyard management (Johnson et al., 2001). Most UAV remote sensing has been conducted using fixed-wing aircraft. UAV helicopters, however, offer the ability to launch without a runway and hover above the intended target for image acquisition. The use of UAVs for agricultural spraying started in Japan in 1990. Miller (2005) used an UAV for dispersing pesticides to reduce human disease due to insect vectors.

Most applications of UAVs in agriculture have focused on remote sensing. Hunt et al. (2005b) developed a high-resolution multispectral digital photography system using UAV. Xiang and Tian (2006, 2007) developed a UAV system for improvement of the spatial resolution, temporal resolution, and reliability of conventional remote sensing platforms. This system was equipped with an azimuth and Differential Global Positioning System (DGPS) sensor system. Fukagawa et al. (2003) developed a Radio-Controlled (RC) helicopter-based crop growth monitor system using a multispectral image sensor. The literature review and personal communications with various researchers did not reveal any published applications of fully autonomous UAVs in agricultural or vector control spray applications. One of the difficulties with using UAVs, is that the licensed pilots of these UAV systems must maintain visual contact with the aircraft throughout all flight operations, which limits the use of UAVs for agricultural spraying over large

fields. The use of fully autonomous and programmable UAVs is expected to overcome this shortcoming.

CSREES-CRIS Search: A CRIS search of active projects related to this project identified several, two of which are from this Research Unit (Ecologically-based Management of Boll Weevils and Post-Eradication Crop Pests [6202-22320-002-00D] and Deployed Warfighter Protection Program [6202-22000-023-06R]). The two Research Units most closely related to this CRIS project are at the Application and Production Technology Research Unit in Stoneville, MS (6402-22000-038-00), and the Application Technology Research Unit in Wooster, OH (3607-21620-006-10). These programs are researching many of the same topics, such as enhanced spray deposition, spray atomization, efficacy, and drift. The Wooster program is geared toward ground, orchard, and greenhouse applications while the Stoneville project has both ground and aerial application elements. While two of the overall objectives of the Stoneville project are closely related to the College Station project, the approaches are different. In the area of precision application, the Stoneville researchers have more experience on image processing, while the College Station researchers are focusing on hardware and nozzle development. In addition to meeting at annual professional meetings to discuss our research projects, all of the SYs from the three projects and our National Program Leader, Sally Schneider, met for two days in Wooster, OH, prior to developing Project Plans. The meeting focused on what types of research projects were being conducted at each location and, most importantly, how we could collaborate with each other to avoid duplication of efforts.

Several of the CRIS projects identified in the search are related to one or more of the specific objectives identified for our project. Spray efficiency through better understanding of nozzle atomization is being investigated at the University of Illinois (ILLU-741-362; PI: Loren Bode). Spray atomization and canopy deposition is being researched at Mississippi State University (MIS-145020; PI: David Smith). Precision application systems related to reduced pesticide use are being researched at the University of California (CA-D-BAE-7098-H; PI: Ken Giles). Our project personnel have had and will continue to have extensive contact with these PIs, as well as with other researchers around the world. As part of our ongoing service to the application community, this project has provided assistance to the recipient of a Small Business Grant (Project No. CALK-2005-03199: A reverse-venturi atomization chamber; PI: Russ Stocker), and plans to evaluate the final product in ARS wind tunnels and in field trials.

Approach and Research Procedures

Objective 1: Improve existing aerial application technologies to maximize efficiency and biological efficacy of crop production and protection compounds with minimal spray drift and impact to non-target systems.

- **Sub-objective 1.A:** Develop and implement standard procedures for evaluating drift reduction technologies (DRTs) and assessing biological impacts of sprays in crop canopies (Hoffmann, Fritz, López).

  Hypothesis 1.A: Technological advances in application technologies can reduce off-target movement of sprays; in addition to reducing drift, systems certified as DRTs will maintain or improve biological efficacy compared to conventional aerial application technologies.

  Experimental Design: Phase I: Establishment of Testing Protocols. Project scientists, working with the EPA and other agencies, will develop and implement testing protocols and data analysis procedures to objectively evaluate drift reduction technologies (DRT). Drift

reduction technologies can be spray nozzles, sprayer modifications, spray delivery assistance, spray property modifiers (adjuvants), **aircraft operating parameters,** and/or landscape modifications. Most of the DRTs tested by project scientists will be evaluated using a high speed wind tunnel, where the measure of performance will be derived from droplet size distribution measurements made using laser diffraction instrumentation. **Initial DRT testing focuses on spray adjuvants marketed as "drift retardants" or "drift control agents." These materials affect the viscosity and dynamic surface tension of the spray solution, thereby affecting droplet size. Testing will focus on changes in spray droplet spectrum, primarily decreases in the volume of spray contained in droplets less than 100 µm (%Vol<100 µm). A 50% or more decrease in %Vol<100 µm will be the criterion for designating a technology as a DRT. Insights gained from this initial DRT testing will be used to develop new technologies or modify existing technologies that qualify as DRT. Initial efforts will focus on developing and/or modifying spray nozzles to make them less prone to generating driftable spray droplets.**

Droplet size spectrum will be measured with the DRT operating at targeted test conditions, which include a specified spray pressure, air speed, and ambient (temperature and relative humidity) conditions. Droplet size measurements will also be made on a reference system (the ASAE S572 reference nozzle associated with the fine/medium boundary; a 110° flat-fan nozzle operated at 44 psi) operating under the same air speed and ambient conditions. Droplet size measurements will be collected with a Sympatec HELOS laser diffraction system (Sympatec Inc., Lawrenceville, NJ). For each set of test conditions a minimum of three replications will be conducted. The full spray volume will be traversed for each replication with each traverse requiring 20 – 30 seconds for completion. The primary operator of the laser diffraction instrumentation control software will input all test parameter information into the software's database system which will tag each test replication with the appropriate identification data. Collected droplet size distribution data will be processed and analyzed to insure that Data Quality Indicator Goals (DQIGs), as specified in the protocol, are met. These DQIGs include guidelines on acceptable variances in spray flow rate (± 0.04 L/min), spray pressure (±3.4 kPa), spray material and air temperature (measured within 0.1 °C), air speed (between 50 and 180 mph measured to within 5 mph), and acceptable standards deviation on the droplet size measurements. **Data will be collected on all parameters affecting DRT performance, which includes spray pressure, nozzle orientation, airspeed, and the physical properties of the spray material (i.e., viscosity and surface tension).** The exact procedures used in these tests are further elucidated in the projects Standard Operating Procedure (SOP) USDA-4.4: Determining Cross-Section Average Drop-Size Distributions of Sprays. Sep. 2007 (see Appendix 2).

Wind tunnel conditions are measured at the same height as the nozzle, upwind of the nozzle in the wind tunnel working section at the time of spray release. These measurements include: ambient air temperature, relative humidity, and air speed. The data will be processed (average and standard deviation data) to insure that DQIGs are met, and recorded electronically and labeled with appropriate process/application parameters. The Data Quality Objectives (DQOs) related to the Good Laboratory Procedures (GLP) requirements of the EPA's DRT program require a minimum of three replications and a standard deviation of less than 7%. This must be met for each system and set of application conditions (spray pressure, air speed, and ambient conditions) intended for actual field use. Wind tunnel and application conditions will be documented using electronic instrumentation and will establish the bounds of the test design.

The measured droplet size spectrum of the DRT system and the reference nozzle, along with the established test condition bounds, will be used to predict deposition downwind of an aerially-applied swath using a spray drift model such as AGDISP. Predicted downwind deposition values from the candidate test systems will be compared to the predicted values from the reference spray system.

Phase II: Field Testing and Bioassay Measurements. A similar system of protocols and data analysis procedures will be developed and implemented for field testing DRTs that cannot be tested using the high speed wind tunnel procedures. These include systems that cannot fit into the existing wind tunnel section or systems that require or operate as a complete unit on the structure of the application aircraft. The measure of performance for a field-tested DRT system will include in-swath and downwind deposition. Agricultural aircraft will be outfitted with the candidate and reference systems and will be used to apply a solution that includes water, a surfactant, and a fluorescent tracer dye. In-swath and downwind deposition will be measured using mylar fallout plates, which can be processed and analyzed in the laboratory for a measure of deposition per area of tracer dye. At a specified distance downwind from the spray line (e.g., 50 m (165 ft), drift towers up to 10 m tall will be erected to ascertain a measure of the airborne component of the spray cloud that may still exist at this distance. A typical field layout for field drift studies is shown in Figure 2 and further detailed in Hoffmann (2006) and Hoffmann et al. (2007).

The candidate DRT system and the reference system will be compared using a combination of established field trial protocols (ASABE Standards S561 [2004]) and the protocols and procedures established in the first two years of this project. **The spray deposition results from the mylar plates at 20 m will be used to determine if a DRT reduces spray drift. If a technology (i.e., adjuvant, nozzle, sprayer) results in a 50% decrease in spray deposition at this location, it will be declared a DRT.** As spray nozzles and DRTs are evaluated throughout the five-year project, atomization models (Kirk, 2007) will be developed that allow users to determine spray droplet size spectra based on their operational parameters.

Based on results from the high speed wind tunnel and field testing of DRTs, the promising DRTs identified will be evaluated for biological efficacy of applications of herbicides, pesticides, plant growth regulators, and crop defoliants under field conditions. Initial tests will include spray applications of herbicide using selected DRTs, a reference system, and a selected conventional application technology. Treatments will be arranged in a mowed grass field as a randomized complete block with a minimum of five replications and will compare on-target deposition and biological impacts. On-target deposition will be assessed using a combination of mylar fallout plates and collected plant structures such as leaves or buds. Biological assessment will be completed using a variety of techniques (dependent on type of application) including aerially-acquired normalized difference vegetative index (NDVI) images, producer-collected yield data, and collection of field insects (including eggs and different developmental stages) which will be evaluated in the laboratory for biological impacts.

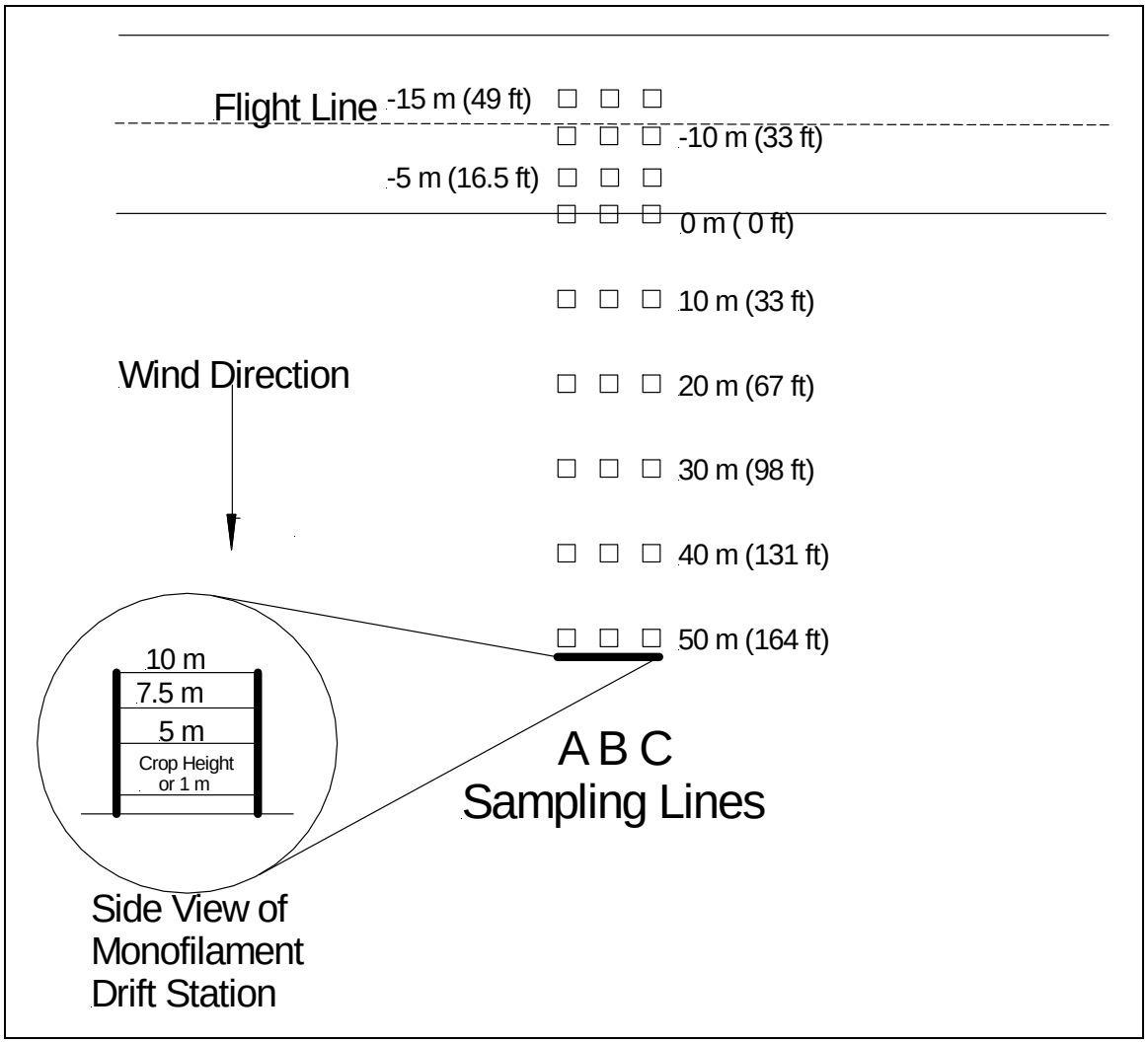

Figure 2. Sample field layout for drift studies.

Contingencies: The EPA's DRT Program is a government program that is subject to all of the funding limitations and constraints of any new program; therefore, the project scientists acknowledge that there may not be an official DRT program in five years. Even in such case, the work detailed in this sub-objective will still contribute to science and the application industry. The protocols and procedures must undergo review by scientific personnel, regulatory agencies, and the public; **therefore, the testing procedure detailed in this Objective may change slightly. The changes** will require adaptation to ongoing research trials; therefore, new methodologies and/or modifications to the physical facilities will be needed to successfully complete this objective. As successful drift reducing technologies are identified, efforts will be directed to gaining a better understanding of the engineering principles associated with these successes and these principles will be further investigated. If new DRTs decrease efficacy of a crop production or protection chemical, these spray technologies **will** be modified to improve efficacy.

Collaborations: None.

- **Sub-objective 1.B:** Develop and optimize the use of autonomous unmanned aerial vehicles (UAVs) for pest control (Hoffmann, Lan, Fritz).

Hypothesis 1.B: Autonomous UAVs equipped with spray systems can be developed to provide effective control of pests, including vectors of human or plant diseases.

Experimental Design: A fully autonomous (does not require licensed pilot) UAV (Rotomotion SR200, www.rotomotion.com) will be fitted with agricultural spray application systems for use in agricultural and vector control applications. An application control system and software routine will be developed to allow users to wirelessly and easily download desired flight patterns from a laptop computer onto the aircraft, which will then perform programmed spray missions. The control system will integrate with the UAV's flight control system to operate the designed spray system within predefined spray blocks. The application system will be composed of a spray pump, nozzles, and tanks for the spray material. An interactive software routine will be developed to optimize the weight capacity of the aircraft (20 kg (50 lb) payload capacity) with the mission specific spray system components, spray mix load, and fuel requirements for the desired flight times.

Nozzle selection is a critical component of the spray system. The nozzles selected must meet the flowrate and droplet size characteristics needed for different applications. For example, vector control applications (i.e., mosquito control) require droplets with a volume median diameter around 20-30 µm, while an insecticide application in soybeans may be optimized with spray droplets with a volume median diameter around 200 µm. The droplet size spectra created by the different spray nozzles will be measured using the protocols developed in Phase I of Sub-objective 1.A. The determination of the effective swath width, application rates, and ultimately effectiveness of control of the UAV applications, will be facilitated by Sub-objective 1.C and will help determine the different configurations of the spray systems on the UAV. Each of these spray systems will be evaluated in the field under different operational parameter settings to analyze the effective swath width and depositional patterns. Following the protocols and procedures established in Phase II of Sub-objective 1.A, field studies will consist of in-swath and downwind deposition measurements made using mylar fallout plates. **For spray deposition comparisons, the UAV spray system will be compared to conventional spray equipment, such as a ground sprayer. The deposition data will be analyzed using PROC GLM in SAS (SAS Institute, 2001) with means separated using Fisher's LSD mean separation technique at a *P*=0.05 significance level. The UAV spray system will be deemed successful if the deposition means are not significantly less than those of the conventional sprayer.**

Airborne spray movement will be measured downwind of the spray swath using active samplers (rotating slides, isokinetic air samplers, and laser diffraction instruments) and passive samplers (horizontal and vertical monofilament strings and soda straws [Fritz and Hoffmann, 2008]). Once the UAV spray system is development, Project Scientists will collaborate with the U.S. Naval Entomology Center of Excellence in Jacksonville, FL to field tests the UAV spray system. The field trials will focus on operational parameters such as spray rate, spray height, and nozzle selection to maximize efficient and efficacious applications for controlling adult mosquitoes. The effectiveness of the sprays will be assessed using caged adult mosquitoes, per standard testing methods, and trap counts from the areas sprayed.

In years 3-5 of the project, the aircraft and spray systems will be deployed in production fields and at military installations to test their application efficiency and efficacy, as well as the rigor of the spray system and UAV under "real world" conditions. The tests on the

military installations will target flying mosquitoes. Assessment of the effectiveness of control will be based on trap counts and bioassay cages deployed during spray applications. Collaborators from the U.S. Navy Entomology Center of Excellence will facilitate this component of the research. Agricultural field tests will emphasize hard to access areas or minor use crops, such as vegetables grown in the area. The acceptance or rejection of the Sub-objective hypothesis will be based on determining success of the UAVs outfitted with application systems in providing efficacious control of the targeted pests. **Specifically, the UAV must provide as good as or better control of targeted pests than conventional spray systems. Statistical differences in insect mortality will be calculated using Fisher's LSD mean separation technique at a *P*=0.05 significance level.**

Contingencies: Though not anticipated, if the fully autonomous mode of the aircraft proves to be cumbersome or if programming flight plans is more difficult than anticipated, new software and control routines may need to be developed by project engineers to make the systems more user-friendly.

Collaborations: Todd Walker and Muhammad Farooq, U.S. Navy Entomology Center of Excellence, Jacksonville, FL (UAV spray system requirements and spray quality measurements)

- **Sub-objective 1.C:** Assess biological impacts of spray drift (Fritz, López, Hoffmann).

Hypothesis 1.C: Biological effects of spray drift can be predicted through laboratory spray table bioassays and accurate field measurements of spray deposition.

Experimental Design: The initial model for this work will focus on exposing greenhouse-grown rye grass samples to simulated spray drift levels *via* laboratory spray table applications. Using glyphosate as a model for future applications, targeted dosage rates of 1, 1/3, **1/10,** 1/33, 1/67, and 1/100 of the labeled application rate will be applied to the plant samples. **As studies progress and other chemicals and species are tested, additional deposition levels will be included to target critical response areas with better precision.** Spray mixes will also contain Caracid Brilliant Flavine FFN, a fluorometric tracer dye. These ranges are consistent with field-collected drift measurements out to 200 m (Fritz, 2006; Fritz and Hoffmann, 2007). These drift deposition levels will be simulated in the automated spray table using a previously developed database relating deposition amount and characteristics (droplet size and percent coverage) to combinations of nozzle type, spray pressure, and application speed. For each deposition level tested, a minimum of ten replications will be conducted. Each replication will consist of a potted rye grass sample and a mylar card. The mylar cards provide a consistent (in terms of spray droplet impaction and collection characteristics) measure of deposition of active ingredient (volume per area) for use is dose-response determinations and comparisons to field study results of spray deposition.

Plant samples will be analyzed at 0, 1, 3, 5, 7, and 14 days after treatment (DAT). Impact on plant health will be assessed *via* NDVI measured by a Fieldspec© (ASD, Boulder, CO) handheld hyperspectral camera. Measures of biological response will be reduction in measured NDVIs and total mortality, as compared to control plants. Mylar cards (10 x 10 cm) will be processed *via* spectrophotofluormetric analysis for deposition of material per area. Results will be used to generate dose-response curves as described by Streibig et al. (1993) and Ray et al. (1999). Results will be databased and used in field study validations as well as support the research in Sub-objectives 3.A and 3.B. After the initial work with

glyphosate and rye grass, additional spray table studies will examine other herbicides on cotton, corn, soybeans, weeds, or other plants of economic or environmental interest. The results and analytical methods from the spray tables will be used in field studies.

Field drift trials will include in-swath and downwind deposition sampling using greenhouse-grown rye grass, mylar fallout collectors, and airborne flux sampling. The use of both plant and fallout collectors will allow for both numerical and biological assessments of spray drift. Layout and execution of these trials will follow protocols established by Fritz (2006), and Fritz and Hoffmann (2007). Glyphosate treatments will be applied at 3 gpa using an Air Tractor 402B outfitted with 25 CP-11TT (CP Products, Inc., Mesa, AZ) flat fan nozzles set to deliver a FINE droplet spray (ASAE, 1999). Spray mixes will also include the Caracid fluorescent dye at 10 g/acre. Based on previous experience with spray drift research, spray trials will be performed in large, unobstructed plots of 40+ acres. This will ensure sufficient area on all sides of the flight line and sampling stations to minimize effects due to surrounding ground cover and prevent off-target damage due to drift of the applied glyphosate. Trials will consist of a minimum of ten replications to account for variations due to operational and meteorological parameters. Field-collected spray flux and mylar deposition samples will be processed *via* spectrofluorometric analysis to determine deposition of material per area. Rye grass samples will be evaluated for biological impacts following the same procedures listed above for spray table work. Field-collected deposition and biological responses will be compared to predicted biological responses based on the dose-response relationships developed under spray table work.

Spray table bioassays of insecticidal spray drift will also be made following the same procedures developed for herbicide work, with the exception of using insects for the biological sampling and assessment. As in the herbicide work, mylar samples will also be placed in the spray table to measure deposition during each replication. The initial insect bioassay work will target a contact insecticide on young corn plants infested with corn leaf aphids and/or broadleaf leaves or ornamentals infested with cotton aphids. Trays of ten plants will make up each sample. The insects will be placed onto plants prior to spray table treatments. Control plant samples will also be infested but not treated in the spray table. A minimum of 30 replications will be made at each simulated drift level. Plants will be examined to determine the number of insects on each plant at 1, 3, 5, and 7 DAT. These bioassay procedures will follow protocols set forth by Martin et al. (2007). This data, along with the mylar deposition data, will be used to develop dose-response relationships. Using the results from the spray tables work, field studies will follow protocols similar to those listed above, again with the exception of using insects for the biological sampling. Estimates of biological impacts based on dose-response spray table bioassays will be validated by linear correlation analysis using field measurements of deposition and biological impacts. As with the spray table insecticide work discussed above, biological samples will consist of young corn plants (10 plants per tray) infested with corn leaf aphids. Similar to herbicide field work, treatments will be applied, samples will be processed, and results of field-measured biological impacts and corresponding drift deposition measurements will be compared to predicted biological responses based on the dose-response relationships developed in the spray table assessments.

Contingencies: If the initial model system of rye grass and glyphosate shows no significant agreement between predicted biological impacts based on spray table developed dose-response relationships and the field-measured data, emphasis will be placed on collecting a greater number of field replications from which additional dose-response relationships will be developed. This will require additional independent field study replications to provide a

dataset to test the additional dose-response relationships. If field study bioassays using container plants infested with insects do not prove practical due to insect movement from plants during transport and collection, insects will be placed on plants after collection from the field and transported to the greenhouse.

Collaborations: None.

Objective 2: Develop remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops.

- **Sub-objective 2.A:** Characterize spatial variability of crop conditions using multispectral imaging to develop treatment maps for use with site-specific aerial application systems (Lan, Martin).

  Hypothesis 2.A: Agricultural aircraft can be equipped with an integrated remote sensing system to measure spatial crop information with sufficient detail to generate prescription maps.

  Experimental Design: An airborne remote sensing system will be developed and tested for use on agricultural aircraft. The system will be designed to capture aerial images of sufficient quality to measure spatial variations of crop health or pest infestation within a field. **The level of quality is defined as the spatial resolution of the on-board digital cameras necessary to differentiate between subtle differences in crop plant health and will vary depending on the objective of the tests.** The system design will emphasize a user-friendly interface for pilot operation and efficiency in converting aerially-acquired images to useful geo-referenced data. A camera control system will be prototyped specifically for aerial imaging using a multispectral camera for integration of camera control computer and software, GIS-based flight navigation software, and GPS-based camera triggering for camera automation and automatic control of roll, pitch, and yaw camera stabilization during the flight, as shown in Figure 3. Irradiance data measured from a ground-based radiometer will be used to normalize imagery. Radiometers, a less cumbersome approach to the traditional standardized reflectance panels, will record solar irradiance and convert recorded solar irradiance and images to milliwatts of energy per square centimeter. The imagining data will then be used to statistically correlate vegetative indices to biological information, such as crop physiological condition, and weed or insect populations from ground measurement. Ultimately, the imagery system will be designed to fit into an application aircraft. **The goal of the image acquisition and processing system is to require no pilot input during flight and automated imaging processing post-flight.**

  To overcome difficulties currently associated with correlating imagery data with what is actually on the ground (a process known as ground truthing), a hyperspectral reflectance instrument will be integrated into the image processing system. This makes it possible to perform multisensor, spectral, temporal, and even multi-resolution data fusion utilizing GIS/GPS techniques to produce high quality prescription maps that can be used to make variable rate applications. The data fusion will be based on new methods for the fusion (Huang et al., 2007) of heterogeneous data, such as numerical or measurable (radiometric, multi-spectral, and spatial information) and symbolic (thematic, human interpretation, and ground truth) data, and will require extensive use of geographic statistics to correlate the data streams. The multisensor data fusion scheme will be integrated into the system through GIS. User-friendly software developed by Project Scientists will be used to convert

the processed remote sensing imagery into prescription maps for site-specific aerial application without extensive user inputs. Successful remote sensing system development will be enhanced through the expertise and personnel support of our Collaborators.

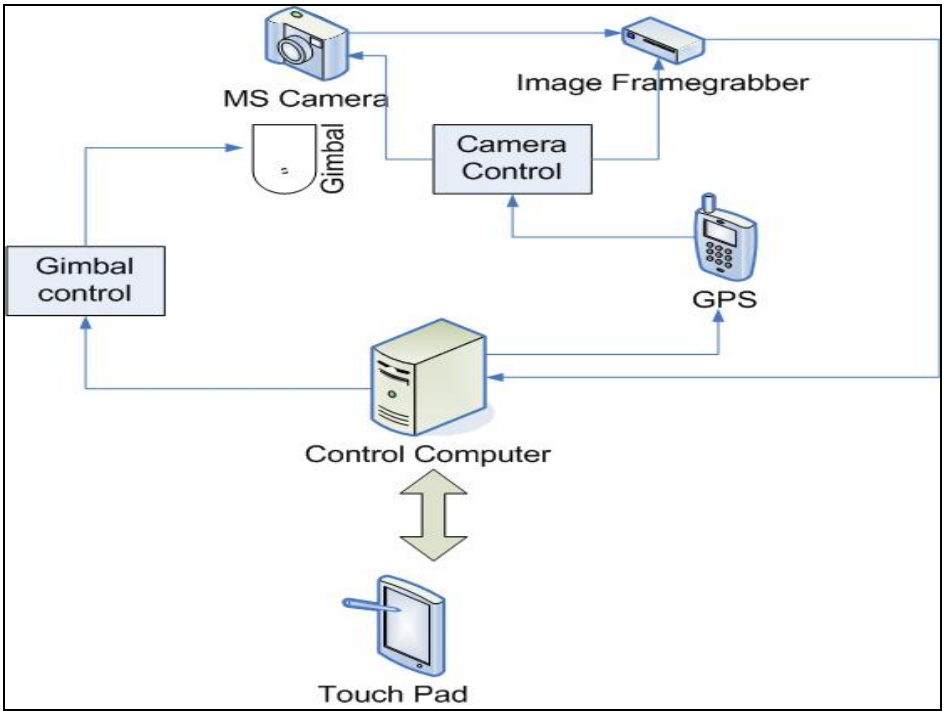

Figure 3. Multispectral camera control system structure.

Contingencies: Current remote sensing systems are expensive and not designed to withstand the extreme conditions under which agricultural aircraft operate; therefore, new enclosures, air filtering and conditioning systems, and shock mediation systems that meet Federal Aviation Administration regulations may need to be created to house the imaging system. The correlation of imagery data, such as NDVI, may require collaboration with other researchers with more experience in assessing crop physiological data. The fusion of the multisensor data stream may require the creation of new software and/or data acquisition equipment.

Collaborations: Ron Lacey, Texas A&M University (multisensor data fusion and personnel support); Yuxin Miao, China Agricultural University, Beijing (remote sensing); Tao Yu, Institute of Remote Sensing, China Academy of Sciences, Beijing (GIS and satellite images).

- **Sub-objective 2.B:** Integrate remote sensing and variable-rate aerial application technologies to optimize crop management strategies (Martin, Lan).

Hypothesis 2.B: An aerial variable rate system can be optimized to deposit agrochemical products at predetermined rates within specified boundaries; variable rate applications will maintain application efficacy as compared to conventional broadcast applications.

Experimental Design: There is a very wide range of aerial application systems currently in operation. Some of these systems will be retrofitted with variable-rate equipment. Typical agricultural aircraft have wind-driven pumps which respond

much slower to rate change inputs than do the much more expensive engine-driven hydraulic pumps. Research needs to be conducted to optimize the variable-rate response of conventional aerial application systems which when commonly flown at speeds exceeding 65 m/s, may indeed only be capable of achieving desired application rates within 40-50 m. Initially, aerial application variable rate technologies (VRTs) will be evaluated for deposition patterns and response times under on-off and variable rate scenarios. This initial system testing will be conducted over either uniform crop canopies or low ground cover (such as a shredded or plowed field). An application flight line will be programmed to turn on and off or vary the application rate at specified intervals. Spray mixes will contain a fluorescent tracer dye to support deposition assessments. In-swath deposition and droplet spectra will be assessed using mylar fallout plates and water sensitive cards. Spray samplers placed at transitional boundaries, where the spray system either turns on/off or changes spray rate, will be placed at shorter intervals (3 – 6 m (10-20 ft)) to provide greater depositional data resolution. Field studies will be conducted at various groundspeeds (193-240 km/hr (120-150 mph)), application rates (0-47 L/ha (0-5 gpa)), and targeted droplet spectra classifications (Medium and Coarse, as defined by ASAE S572 [1999]) with five replications per set of conditions. Application rate change treatments will include no-to-low, low-to-high, high-to-low, low-to-no, no-to-high, and high-to-no. Dependent variables of interest will be as-applied deposition (mylar), droplet size deposited on water sensitive paper (WSP), rate of change in transitional zones, and volumetric median diameter (VMD). The rate of change is defined as the time and distance required to turn on/off or make a rate change (i.e., from two gallons per acre [gpa] to four gpa) in the system. The precision with which the system targets a specified spray rate boundary also will be determined. Systems will be deemed acceptable if target rate is achieved within 50 m. Appropriate mixed-model methodology will be used to analyze the data.

VRT systems deemed acceptable, and that are appropriate for a given application (based on recommended or labeled droplet spectra and application rate), will be tested and compared to optimal single rate applications. Prescription maps, which define the amount and location of material to be applied across a field, will be generated for the fields in the variable rate tests. Actual in-swath deposition and droplet size will be determined by mylar deposition plates and WSPs **at 5-m intervals** located throughout each defined application rate block. **Quantitative analysis of deposition data from samplers in known locations along with geo-referenced as-applied data will be used to assess accuracy of the variable-rate aerial application systems.** The field measured application data will be statistically analyzed against the prescribed application rate using geo-statistical software such as “R” and GeoDA to determine the accuracy of the variable-rate application. Applications for pre-plant weed burn down, plant growth regulation, and cotton defoliation will be targeted in these studies. Biological efficacy from each treatment will be determined *via* remote sensing to assess crop uniformity, while crop yield data will be collected by cooperating producers. Using the measured deposition, efficacy, and crop yield data, VRT technologies will be compared to conventional broadcast applications. Fuel and operational savings will be calculated and compared between application systems. An acceptable variable-rate aerial application system will provide the targeted application rate (±10%) within the defined spray block while maintaining a consistent droplet spectra classification (i.e., fine, medium, or coarse classification) and equivalent or increased biological efficacy and yield.

Contingencies: This work is dependent on integration of variable rate application components that are presently available on the market or are being developed. If a limited number of components and/or systems are available at project initiation, the work as

proposed will go forward. Depositional pattern and off-target movement assessments can be performed as technology becomes available. **Project scientists will use the close collaboration between this Project and the related Project in Stoneville, MS, to resolve any problems that may arise which would otherwise prevent this Objective from being completed successfully.**

Collaborations: Steve Thomson, ARS Application and Production Technology Research Unit, Stoneville, MS (remote sensing and precision application expertise).

- **Sub-objective 2.C:** Develop sensors that rapidly and/or remotely detect pest presence, crop condition, spray droplets, and volatile organic compounds (Lan, Hoffmann).

  Hypothesis 2.C: Sensors and instruments can be developed to detect volatile organic compounds associated with insect pest infestations and pesticide applications. Existing and developed sensors can be integrated to characterize crop physiological condition in real-time.

  Experimental Design: Development of E-Nose: An instrument, commonly called an E-nose or electronic nose, will be developed for collecting, monitoring, and recording gas emissions for the presence of volatile organic compounds **(VOCs). In developing this sensor, the design criteria will be: 1) an inexpensive sensor (i.e., <$200 to build); 2) a sensor that is highly adaptable to detecting different compounds; and 3) a software interface that is Windows-based and will allow for real-time detection of VOCs.** Volatile organic compounds (VOC) that indicate the presence of insect pest infestations, insect plant damage, and pesticide applications will be identified from available literature and through gas chromatography analysis. The first step is to develop a method to collect the gas emissions in a confined space. **For the initial testing, specific solvents, such as acetone, hexane, benzene, and Aromatic 150, will be held in glass Erlenmeyer flasks. The sensor will be placed in the headspace to detect the volatilized solvents.** Next, a means of recording the gas measurement data automatically via a computer program will be developed. Instrument development involves assembly of the sensor chamber and connections between the chamber and data collection system. Gas sensors will be mounted in the ceiling of the chamber and linked to a circuit board placed on top of the chamber, which will be connected to the power source. Insects, plants, or pesticides will be placed in the chamber to generate VOCs. **Controlled-release technology will also be used to release a volatile of interest at a constant rate. An air sampler containing suitable adsorbent material will be used in line with the electronic nose to trap the volatile of interest and determine its concentration.** A data acquisition module will be used to convert the output from the gas sensors to digital output for recording and analysis. The data will be processed using principal component analysis, discriminate analysis, and other analyses based on statistical pattern recognition and artificial neural networks. The system hardware, software, and platform will be tested using the compounds of interest at differing levels of concentration to ensure proper system functionality. **Successful completion of this Sub-objective will be the development of an E-nose that can detect chemicals that are volatilized from pesticides and emanate from insects, such as stinkbugs.**

  Integration of Crop Physiology Measurement Sensors: An integrated sensor and instrumentation system will be developed to measure real-time crop conditions including NDVI, biomass, crop canopy structure, and crop height. Individual sensor components will be calibrated and tested under laboratory and field conditions prior to system integration.

The integration system includes crop height sensor, crop canopy analyzer for leaf area index and PAR (Photosynthetically Active Radiation), NDVI sensor, multispectral camera, and a hyperspectral radiometer, as shown in Figure 3. The system will be interfaced with a DGPS receiver to provide spatial coordinates for all sensor readings. Data will be imported into a GIS for georeferencing and statistical analyses purposes. Multisensor data fusion will integrate and analyze data from these sensors to provide an assessment of crop structure and environment. Successful sensor and instrument development **and completion of this Sub-objective** will rely on the expertise, facility, and personnel support of our Collaborators.

Contingencies: If the indicator organic compounds prove difficult or extremely time consuming to detect, E-nose development and testing will go forward using the few identified pest detection compounds presently available in the literature. Execution of this process for one compound will facilitate the development process for future compounds as they are identified. It is anticipated that the compound identification and E-nose tuning to these compounds will be an ongoing component of this research. If integration of the multisensor data fusion system proves successful early on, it will be incorporated and used to support other sub-objectives targeting biological assessments of spray deposition and drift.

Collaborations: Ron Lacey, Texas A&M University (sensors for crop conditions); Heping Zhu and Richard C. Derksen, USDA-ARS, Wooster, OH (integrated sensor and instrumentation system); Yuxin Miao, China Agricultural University, Beijing (sensors for crop conditions); Jin Tong, Jilin University, Changchun, China (E-nose development).

- **Sub-objective 2.D:** Optimize autonomous unmanned aerial vehicles (UAV) for remote sensing of crop conditions (Hoffmann, Lan).

  Hypothesis 2.D: Autonomous UAVs can be equipped with an integrated remote sensing system to measure spatial crop information with sub-meter spatial resolution to generate prescription maps.

  Experimental Design: Remote sensing systems will be developed that can be placed on the project's two fully autonomous UAVs (helicopters). These vehicles can be transported directly to the field site or sent *via* a preprogrammed flight plan developed under Sub-objective 1.B and will provide near real-time remote sensing information. **The goal is to develop the UAV platform with remote sensing systems that can be operated by a crop consultant or farmer. The system will be easy to transport, safe to operate, and the imaging system will generate near real-time data that can be used to assess the state of the crop.** Initial remote sensing efforts will focus on a multispectral camera, which is used to calculate NDVIs for an individual field. Spatial resolution is a measure of the detail captured in an image. An aerial image with 1-m resolution would have a pixel size that represents 1 m by 1 m. While aerial imaging systems currently exist which can provide this level of spatial resolution, quality is many times sacrificed. With a given multi-spectral camera, higher spatial resolution is achieved by reducing altitude. When altitude is reduced with a fixed-wing aircraft platform, the effects of ground speed increase, which can cause pixel blurring. In addition, high resolution images can be obtained by mosaicing or stitching several low-altitude images together. Unfortunately, this process is complicated and introduces errors due to different lighting conditions for each image that is mosaiced. A rotary-wing (helicopter) aircraft is ideal for aerial imaging because it provides a stable platform where the necessary altitude can be selected to provide the highest resolution possible while ensuring image quality. **Image processing and field calibrations will be**

done using the techniques developed in Objective 2.A. Specifically, the imaging data will be used to statistically correlate vegetative indices to biological information, such as crop physiological condition, and weed or insect populations from ground measurements.

Current remote sensing equipment exceeds the operational payload of the project's autonomous aircraft; therefore, project scientists will modify, or work with collaborators to modify, existing equipment. This will require miniaturization of the imaging system and/or use of low weight but high strength materials. Acquisition software will also be developed to operate the new remote sensing system. This software will generate prescription maps that can be used in field spray applications. Image processing and prescription map development will be done in conjunction with activities performed under Sub-objective 2.A. The measure of success for this work is the development and integration of a remote sensing system onto the project's rotary UAV that can be used to capture crop condition data, such as NDVIs, with a spatial resolution of less than one meter. Once the maps have been generated, they will be used in the precision application equipment in Subobjective 2.B.

Contingencies: If the fully autonomous mode of the aircraft proves to be cumbersome, or if programming flight plans is more difficult than anticipated, new software and control routines may have to be developed by project engineers to make the systems more user-friendly. Project scientists may have to use different spectral bands from different cameras if significant weight reductions with existing camera systems cannot be achieved. The autonomous vehicles can also be fitted with the sensors that will be developed under Sub-objective 2.C.

Collaborations: None.

Objective 3: Develop, enhance, and implement decision support systems that improve user ability to select and operate application equipment and schedule spray treatments that optimize biological efficacy.

- **Sub-objective 3.A:** Correlate aerial spray dispersion model estimates with off-target biological effects and in-swath deposition results (Fritz, Lan, López, Hoffmann, Martin, Westbrook).

  Hypothesis 3.A: Spray dispersion model outputs can be used to predict the biological impact on targeted and non-targeted plants in-swath and downwind from a spray application.

  Experimental Design: The initial framework for this objective will focus on comparing AGDISP modeled in-swath and downwind deposition predictions to high quality field-collected deposition data. Data needed to run the AGDISP model includes application height, wind speed, wind direction, temperature, spray parameters, canopy and terrain characteristics. The initial data used is anticipated to be that collected from the herbicide field trials conducted as part of Sub-objective 1.C. These datasets will contain complete operational characteristics, in-swath and downwind deposition, as well as coinciding biological impacts as measured from rye grass samples. The operational data measured during each replication of these trials will be input to AGDISP, and depositional data corresponding to field-measured deposition locations will be generated. Correlation analyses will be used to develop relationships between the AGDISP predicted deposition

data and the field-collected deposition data will be determined. Using the dose response relationships developed under Sub-objective 1.C, biological impacts will then be predicted from the AGDISP predicted deposition data. This initial work will determine the biological impact predictive capabilities of the coupling of AGDISP with dose-response relationships under ideal conditions.

Following the initial work, usable data sets (those that include sufficient data for input into AGDISP and biological response data) from previous years' and current year's research dealing with cotton defoliation and/or weed control will be compiled and spray drift model estimates of in-swath deposition from AGDISP will be generated. Using field-collected data and/or spray table data, dose response relationships will be generated. Predictions of biological response will be made based on AGDISP deposition predictions. These will be compared to the field-measured biological responses. The cotton defoliation or weed control trials conducted under Sub-objectives 1.A or 2.B will provide the bulk of the data for this portion of the work. Spray table evaluations, following procedures detailed under Sub-objective 1.C, may be needed to develop the dose-response relationships if sufficient field data is not available. These evaluations will use container-grown plants to bioassay impacts of deposition of the active ingredient at the levels measured in these studies. Additional dedicated field studies, following protocols detailed under Sub-objectives 1.A and 2.B, may be performed depending on data availability. The measure of success will be derived from the comparisons of the predicted biological impacts based on the AGDISP modeled deposition values and the field-observed deposition and biological impacts.

Contingencies: If initial work comparing field-collected biological impact data from glyphosate and rye grass studies and predicted biological impact based on AGDISP predicted depositions and dose-response relationships do not show significant agreement, efforts will continue to focus on these best case conditions rather than shifting focus to defoliation of weed control studies.

Collaborations: None.

- **Sub-objective 3.B:** Develop and implement crop growth and management decision support systems to optimize aerial applications (Lan, Hoffmann, López, Fritz, Martin).

Hypothesis 3.B: Crop physiological, geographical, and application technology information can be integrated into a management decision support system for making crop management and application decisions.

Experimental Design: A Windows interface will be designed and tested for a crop growth and pest management model called ICEMM (Integrated Crop Ecosystem Management Model) and provided to users *via* the web and/or CD. The interface will be the first in allowing additional integration of remotely sensed data into a crop growth model. Extensive field verifications and correlations using geospatial statistics *via* database compilation and analyses will be required to verify the integrity of the new model created as a result of this work and will be an iterative process. Using research results from Objectives 1 and 2, a crop model will be developed and linked with a spray dispersion model to predict spray deposition within a field based on crop structure. The interaction and quantification of spray deposition will increase the usability and functionality of both models.

The development of application decision support systems (DSS) will be the riskiest part of the research proposed by the project and will rely on research results from nearly every

component of the Project Plan. The DSS will be developed with an open structure that can continuously incorporate new data, information, and computation techniques, as shown in Figure 4. The system will include: 1) a database which contains the data related to crop growth and pest management; 2) linkage to GPS ground truth data and processed remote sensing imagery; 3) a model base which contains models that are able to provide information for optimizing crop growth and routine management; 4) a method base which contains methods of pattern recognition, statistics, and soft computing (i.e., fuzzy logic and artificial neural networks); 5) a knowledge base containing if-then rules for symbolic decision making incorporating subjective judgments; and 6) a user interface for research users, extension agents, aerial applicators, crop consultants, and farmers. Successful DSS development will rely on the expertise and personnel support of our Collaborators.

Contingencies: While a complete and verified decision support system may not be completed under this 5-year project, each of the subcomponents will contribute to the advancement of science and will impact users.

Collaborations: Ron Lacey, Texas A&M University (decision support systems); Yuxin Miao, China Agricultural University, Beijing (crop modeling).

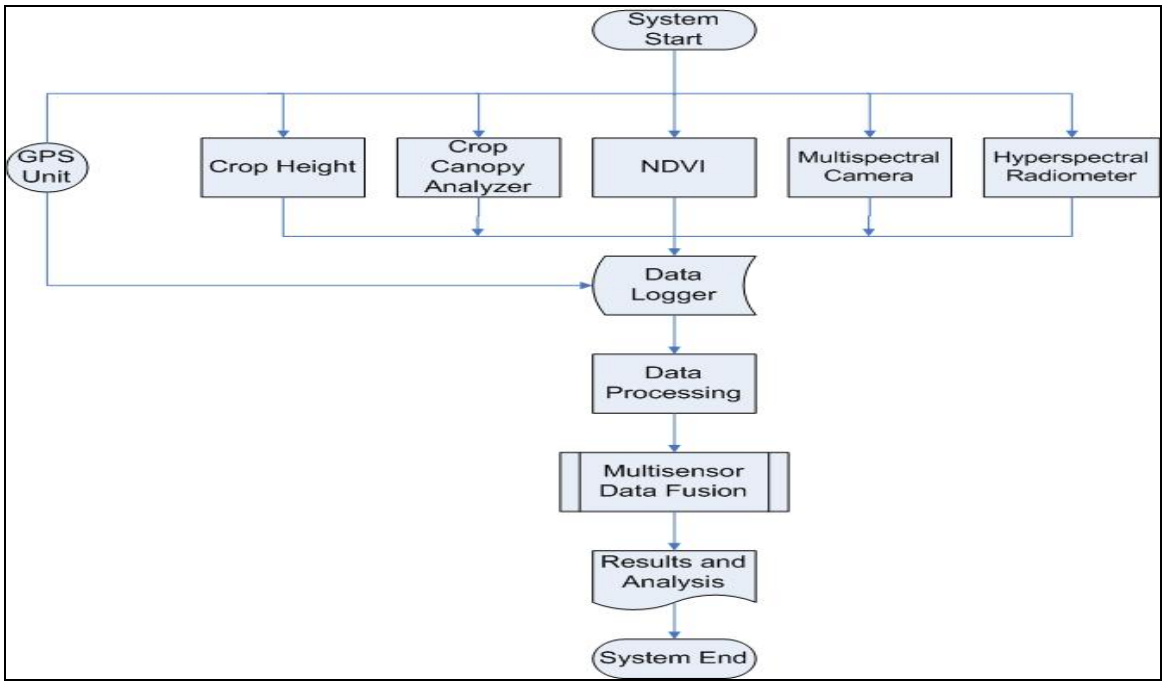

Figure 4. Sensor integration system for measuring crop conditions.

Physical and Human Resources

The objectives detailed in this proposal are achievable by the personnel assigned to this project. These include 5.1 SY (Fritz, Hoffmann, Lan, López, Martin, and Westbrook [10%]), one Category 3 scientist (Latheef), one PFT pilot (Denham) and five FTE (full-time-equivalent) ARS technicians. Personnel from other projects within the Unit will assist, as appropriate, when needed to complete large, labor-intensive field trials.

The physical resources available to this project include offices, six laboratories, a greenhouse, insect rearing facilities, and an automated spray table located at the Southern Plains Agricultural Research Center in College Station, TX. The group also has office space, four hangers, a full machine shop, mixing/loading pad with a bioremediation tank, chemical storage facilities, and three wind tunnels with test sections of 1-ft², 9-ft², and 36-ft² located at the Riverside Campus of Texas A&M University in Bryan, TX. Airspeeds from 0.5-170 mph can be generated in the various tunnels to simulate both ground and aerial application conditions. These wind tunnels represent a unique collection of resources within the U. S. and one of only five known in the world. Through past and ongoing working relationships with farmers throughout Texas, the project also has access to large blocks of land as needed for specific research projects.

The project has the application and scientific equipment necessary to accomplish the stated objectives. The Unit's three fixed-wing (AirTractor 402B, AgHusky 188, Cessna 206) and one rotary-wing (Hiller 12E) aircraft are flown by the project's pilot. These aircraft are representative of those used in most cropland aerial applications. The AirTractor is currently equipped with an Aircraft-Integrated Meteorological Measurement System (AIMMS-20) that provides real time meteorological measurements and is interfaced with the Adapco Wingman automated spray system. The AgHusky also has GPS/GIS interface and variable rate capabilities through the installed DelNorte guidance and application system. The Cessna 206 aircraft will be primarily used for the remote sensing studies, which use a Geospatial Multispectral Camera (MS4100) coupled to a TerraHawk camera control system. These three aircraft will be used extensively in all field studies and remote sensing activities. The project also has two fully autonomous UAVs (Rotomotion SR20, Rotomotion SR200) for use in the proposed UAV projects. Meteorological equipment, including sonic anemometers and meteorological tower stations, will be utilized during all deposition and drift studies.

For the remote sensing studies, the project has several pieces of relevant equipment. A GreenSeeker hand-held optical sensor (Model 505, NTech Industries, Inc.) for measuring NDVI data will be used in spray table and field trials. A hyperspectral radiometer (Model Fieldspec handheld 325-1075nm, ASD, Inc.) will be used to measure plant reflectance wavelength. A Sunscan canopy analysis system (Model SS1, Delta-T Devices, Ltd.) will be used to measure LAI (Leaf Area Index), and incident and transmitted PAR (Photosynthetically Active Radiation) in plant canopies.

The project has a 3D stereo-microscope with stain size and fluorescent image analysis capabilities. For additional image analyses needs, an in-house imaging system coupled to a National Instruments imaging program and a commercial scanning system (WRK, Inc., Droplet Scan) are used. For analyses of various samples, the project has colorimeters, fluorometers, and a gas chromatograph with auto sampler. Droplet size measurements are made using various laser particle measuring systems (Sympatec Helos laser diffraction instrument, LaVision SprayMaster, Particle Measuring Systems). Airspeed and air turbulence measurements are assessed using a hot-wire anemometry system equipped with numerous 1-, 2-, and 3-D probes.

The project has several trucks and vans that are utilized for various research projects. A mix/ load trailer is used when conducting field trials at remote locations.

Project Management and Evaluation

The ARS scientists assigned to this project will meet formally as a team on a regular basis to discuss progress, evaluate achievement of stated goals and objectives, and explore ways to improve cooperation and collaboration. Scientists assigned to each sub-objective will meet with their respective collaborators as appropriate to review collected data and discuss changes needed to improve the quality of the research and will maintain ongoing communication *via* phone and email. Frequent, informal team meetings will be led by the Project Lead Scientist. The SYs in this project have developed into an excellent and productive team during the previous project and this effective teamwork will be maintained. The Research Leader will be kept informed of any significant changes made in the experimental approaches and of any deficiencies in resources that would impede achievement of stated objectives. The Research Leader will be informed when contingencies are used or when there is a change in research direction. Changes will be documented in the research plan and annual report. If significant changes in research direction are made the Southern Plains Area Director and National Program Leaders will be informed *a priori*. Collaborators will be consulted and a consensus agreed upon before any changes are made to the relevant objectives. In addition, progress will be assessed and documented *via* milestone tables in the project plan and annual report.

Milestones

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 1	Improve existing aerial application technologies to maximize efficiency and biological efficacy of crop production and protection compounds with minimal spray drift and impact on non-target systems		
Subobjective 1.A	Develop and implement standard procedures for evaluating drift reduction technologies (DRTs) and assessing biological impacts of sprays in crop canopies		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest Management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Technological advances in application technologies can reduce off-target movement of sprays. In addition to reducing drift, systems certified as DRTs will maintain or improve biological efficacy compared to conventional aerial application technologies	CH, BF, JL	12	Develop and submit SOPs and protocol for testing DRTs in high-speed wind tunnels to EPA and scientific community for review		Published testing protocols and procedures for high speed wind tunnels
	CH, BF, JL	24	Initiate testing of DRTs using established protocols Develop and submit SOPs and protocol for testing DRTs in low-speed wind tunnels and field trials to EPA and scientific community for review		Screening of several potential DRTs Published testing protocols and procedures for field studies
	CH, BF, JL	36	Field tests of technologies that qualified as drift reduction technologies in wind tunnel tests		DRTs are shown to result in significant reduction in off-target movement of sprays
	CH, BF, JL	48	DRTs are field tested to assess their impact on biological efficacy		DRTs are demonstrated to maintain or improve biological efficacy of a pesticide
	CH, BF, JL	60	Use testing systems to evaluate recently introduced or created DRTs		New DRTs are adopted by applicators

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 1	Improve existing aerial application technologies to maximize efficiency and biological efficacy of crop production and protection compounds with minimal spray drift and impact on non-target systems		
Subobjective 1.B	Develop and optimize the use of autonomous unmanned aerial vehicles (UAVs) for pest control		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Autonomous UAVs equipped with spray systems can be developed to provide effective control of pests, including vectors of human or plant diseases	CH, YL, BF	12	Develop spray system for UAV Develop computer programming flight control interface for inputting flight plans		A working prototype of spray system User-friendly interface for inputting flight plans
	CH, YL, BF, TW	24	Evaluation of spray system in field trials Develop a UAV application system for granular applications.		Characterization of droplet size, swath width, and other performance elements of the spray system
	CH, YL, BF, TW	36	Test UAV spray system under actual crop production and vector control conditions		UAV system will be deployed to personnel outside of ARS for use; i.e., military installation to collaborators
	CH, YL, BF, TW	48	Further refinement of spray systems Explore use of new UAVs that have been introduced to the marketplace		Deliver UAV spray systems to users, particularly the Deployed Warfighter Protection Program
	CH, YL, BF, TW	60	Incorporate UAV spray systems into commercial production system and deployed overseas		UAV systems deployed to overseas operations

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 1	Improve existing aerial application technologies to maximize efficiency and biological efficacy of crop production and protection compounds with minimal spray drift and impact on non-target systems		
Subobjective 1.C	Assess biological impacts of spray drift		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Biological effects of spray drift can be predicted through accurate spray deposition measurements	BF, JL, CH	12	Developed protocols for spray table bioassay of herbicidal drift deposition levels		Method for chemical/plant species dependent spray drift level bioassays
	BF, JL, CH	24	Spray table bioassays and development of dose-response curves; generation of field-collected drift deposition and biological impact data		Database of glyphosate/rye dose-response relationships and field-collected data
	BF, JL, CH	36	Developed protocols for spray table bioassays to develop dose response relationships for insecticides; additional field-collected herbicidal bioassay and drift data		Method for chemical/insect dependent bioassays and development of dose response relationships; additional field data and initial field validation of spray table herbicide bioassays
	BF, JL, CH	48	Additional field studies collecting drift deposition and biological response data for comparison to developed dose/response data and additional spray table and field-collected dose/response data		Expanded library of dose-response relationships and field-collected drift and biological response data
	BF, JL, CH	60	Comparisons of dose/response predicted biological response data and field-collected biological impact data		Dose response relationships for tested chemical/species pairings

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 2	Develop remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops		
Subobjective 2.A	Characterize spatial variability of crop conditions using multispectral imaging to develop treatment maps for use with site-specific aerial application systems		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System; Problem Statement 1A.4: Develop Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Agricultural aircraft can be equipped with an integrated remote sensing system to measure spatial crop information with sufficient detail to generate prescription maps	YL, DM	12	Test and establish an airborne multispectral imaging system that is able to automatically acquire images with camera stability over crop fields		A system prototype that integrates the functions of the multispectral camera, camera automation and irradiance measurement
	YL, DM, YM, TY	24	Develop image processing methods to produce vegetation indices and image classifications Statistical analysis between image features and field measurement of crop growth and pest infestation		Methods and procedures of image processing and statistical analysis used to characterize crop growth and pest issues
	YL, DM, RL, YM, TY	36	System evaluation with crop field flight-over and ground measurement for crop growth observation and pest infestation identification over a year		Hardware and software for system operation and data analysis
	YL, DM, RL	48	Develop multisensor data fusion scheme to combine data from airborne images and ground truth		Method of multisensor data fusion to improve the quality of airborne image data
	YL, DM, RL, YM, TY	60	Optimize the imaging system and improve the methods and procedures as necessary through more testing and applications		Deliver aerial image data for prescription of side-specific application and pest issue identification to provide customer service

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 2	Develop remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops		
Subobjective 2.B	Integrate remote sensing and variable-rate application technologies to optimize crop management strategies		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System; Problem Statement 1A.4: Develop Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
An aerial variable rate system can be optimized to deposit agrochemical products at predetermined rates within specified boundaries; variable rate applications will maintain application efficacy as compared to conventional broadcast applications	DM, YL	12	Development and testing of commercially-available variable-rate aerial application components and/or systems		Field validation data for commercially available variable-rate aerial application components and/or systems
	DM, YL, ST	24	Continued development and testing of variable-rate aerial application components and/or systems		Additional field validation data for variable-rate aerial application components and/or systems Protocols and experimental design for prescription-based field trials
	DM, YL, ST	36	Prescription-based field testing of variable-rate aerial application systems		Field data for prescription-based trials Protocols and experimental design for biological efficacy field trials
	DM, YL	48	Biological efficacy field studies using tested variable-rate aerial application systems		Deposition and efficacy data for tested variable-rate aerial application systems
	DM, YL	60	Optimization of variable-rate aerial application systems		Adoption of variable-rate systems by aerial applicators

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 2	Develop remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops		
Subobjective 2.C	Develop sensors that rapidly and/or remotely detect pest presence, crop condition, spray droplets, and volatile organic compounds (VOC)		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System.		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Sensors and instruments can be developed to detect volatile organic compounds associated with insect pest infestations and pesticide applications. Existing and developed sensors can be integrated to characterize crop physiological condition in real-time	YL, CH, RL, JT, YM	12	Identify VOCs that indicate the presence of insect pest infestations, insect plant damage, and pesticide applications		Set up VOC data base for indicating the presence of insect pest infestations, insect plant damage, and pesticide applications
	YL, CH, RL, HZ, RD, JT, YM	24	Develop VOC instrument system, E-nose system, and an integrated sensor and instrumentation system		Prototype system for VOS measurement, E-nose, and plant biomass real-time measurement
	YL, CH, RL, JT, HZ, RD	36	System evaluation for VOC E-nose and plant meter with crop field for crop growth observation and pest infestation identification over a year		Hardware and software for system operation and data analysis
	YL, CH, RL, HZ, RD, YM	48	Continue to modify the VOC and E-nose system, and develop multisensor data fusion scheme to combine data from different sensors in plant meter		Patent applications for VOC meter, E-nose, and plant meter; method of multisensor data fusion to improve the quality of sensor system
	YL, CH, RL, HZ	60	Optimize the VOC, E-nose, and plant meter and improve the methods and procedures as necessary through more testing and applications		Deliver VOC, E-nose, and plant meter to users; publish findings

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 2	Develop new remote sensing and variable rate aerial application systems that enhance detection, prevention, and control of plant diseases, nutritional deficiencies, or insect damage in annual and perennial crops		
Subobjective 2.D	Optimize autonomous unmanned aerial vehicles (UAV) for remote sensing of crop conditions		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.2: Develop Automation and Mechanization Systems and Strategies to Optimize Pest management, Improve Crop Yield and Quality, Reduce Worker Exposure, and Protect the Environment While Maintaining a Profitable Production System; Problem Statement 1A.4: Develop Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Autonomous UAVs can be equipped with an integrated remote sensing system to measure spatial crop information with sub-meter spatial resolution to generate prescription maps	CH, YL	12	Develop and test lightweight, multi-spectral imaging system		Lightweight, multi-spectral imaging system for UAV
	CH, YL	24	Selection of appropriate imaging system components and testing of system's ability to complete autonomous imaging missions		Flight test data for UAV imaging system Color-infrared images of crop production fields
	CH, YL	36	Optimization of system and image acquisition software		Hardware and software for system operation and data analysis
	CH, YL	48	Incorporation of remotely sensed data into field spray applications		Prescription maps based on UAV-acquired remote sensing data
	CH, YL	60	Capability development for multiple remote sensing missions Investigation into additional applications of UAV-acquired remote sensing data		Multiple remote sensing mission capability Identification of additional applications for UAV acquired images Peer-reviewed publications documenting UAV research

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 3	Develop, enhance, and implement decision support systems that improve user ability to select and operate application equipment and schedule spray treatments that optimize biological efficacy.		
Subobjective 3.A	Correlate aerial spray dispersion model estimates with off-target biological effects and in-swath deposition results.		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.3: Decision Support Systems to Optimize Pest Management		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Spray dispersion model outputs can be used to predict the biological impact on targeted and non-targeted plants in-swath and downwind from a spray application	BF, YL, JL, CH, DM, JW	12	Gather and inventory available dose/response relationships and field-collected data		Database of field and dose/response data
	BF, YL, JL, CH, DM, JW	24	Use AGDISP to develop predicted deposition values for sampling locations used in rye grass/glyphosate field studies (Sub-objective 1.C); use developed dose/ response curves to predict biological effects		New database of modeled versus predicted deposition and biological impact data
	BF, YL, JL, CH, DM, RL, YM, JW	36	Continued AGDISP model predictions of deposition for field-collected data and generation of biological response predictions		Continued database expansion
	BF, YL, JL, CH, DM, RL, YM, JW	48	Continued AGDISP model predictions of deposition for field-collected data and generation of biological response predictions. Data compilation and AGDISP predictions for defoliation and/or weed control field studies		Continued database expansion and comparison of AGDISP and dose/response curve predicted biological impact data
	BF, YL, JL, CH, DM, RL, YM, JW	60	Correlation of modeled data with field-collected data		Database of modeled data correlated to field biological response data

Project Title	Aerial Application Research for Efficient Crop Production	Project No.	6202-22000-023-00D
National Program	NP 305 Crop Production		
Objective 3	Develop, enhance, and implement decision support systems that improve user ability to select and operate application equipment and schedule spray treatments that optimize biological efficacy.		
Subobjective 3.B	Develop and implement crop growth and management decision support systems to optimize aerial applications		
NP Action Plan Component	Component 1: Integrated Sustainable Crop Protection Systems		
NP Action Plan Problem Statement	Problem Statement 1A.3: Decision Support Systems to Optimize Pest Management Problem Statement 1B.2: Develop Mechanization and Automation Practices that Increase Production Efficacy		

Hypothesis	SY Team	Months	Milestones	Progress/ Changes	Products
Crop physiological, geographical, and application technology information can be integrated into a management decision support system for making crop management and application decisions	YL, CH, JL, BF, DM	12	Update crop management model-ICEMM to Windows XP version		Software CD available on request
	YL, CH, JL, BF, DM	24	Compilation of field-collected and remote sensed data from aerial imagery		Database of field-collected and remote sensed data from aerial imagery and inclusion of modeled response data
	YL, CH, JL, BF, DM	36	Continued data compilation, generation of new data through field studies and aerial imagery		Continued database expansion
	YL, CH, JL, BF, DM	48	Field studies collecting required biological response using sensor system developed under 2.C, and model input parameters; begin correlation of field data with model predictions		Collection of targeted field biological response data and development of methodology for comparing field data to model predicted data
	YL, CH, JL, BF, DM	60	Correlation of modeled data with field-collected data		Database of modeled data correlated to field biological response data to support decision support system

Project Team Members:

CH-Clint Hoffmann
BF-Brad Fritz
YL-Yubin Lan
JL-Juan López
DM-Dan Martin
JW-John Westbrook
TW-Todd Walker
RL-Ron Lacey
YM-Yuxin Miao
TY-Tao Yu
ST-Steve Thomson
HZ-Heping Zhu
RD-Richard Derksen
JT-Jin Tong

Accomplishments from Prior Project Period

Terminating ARS Research Project Number: 6202-22000-023-00D
Title: Aerial Application Technology for Crop Production and Protection
Project Period: September 24, 2003 to September 23, 2008
Investigators and FTE

Wesley C. Hoffmann, Lead Scientist	1.0
John K. Westbrook, Research Leader	0.1
Juan D. López, Jr.	1.0
Bradley K. Fritz (Hired in 2002)	1.0
Ivan W. Kirk (Retired in 2004)	1.0
Daniel E. Martin (Hired in 2004)	1.0
Yubin Lan (Hired in 2005)	1.0

Project accomplishments and impact including: Over the past five years of this project, three new SYs have committed their expertise to ARS and the aerial application industry. The synergy created with the addition of these scientists has increased the project's productivity and impact, as demonstrated by the dramatic increase in publications and presentations over the last two years. We continually listen to the needs and concerns of the aerial application industry and producers, and strive to address these issues with sound and objective research. This project recently sponsored an ARS booth at the National Agricultural Aviation Association National Meeting and Trade Show, during which we interacted with numerous aerial applicators and other attendees, informing them of our past research accomplishments, our projected research objectives and, most importantly, sought their feedback regarding how we could best address their needs. We received significant positive feedback as well as comments, concerns, and suggestions of new ideas for projects and issues that would allow our group to better serve the application industry. Many of these are incorporated into this Project Plan. A copy of the display that was used at the Trade Show is shown in Appendix 3. The empty space in the middle of the poster (5 ft long and 8 ft wide) was used to show a rolling presentation of past research projects. Specific accomplishments under the prior project are discussed below.

Objective 1: Develop and evaluate nozzles and other application technologies and spray formulations that reduce driftable fines and improve efficacy. At the request of the National Agricultural Aviation Association, 22 atomization models for spray nozzles commonly used on fixed and rotary wing aircraft were developed. These models were translated into an interactive Excel spreadsheet and made available *via* CD, a printed handbook, and the Project's website (http://apmru.usda.gov/downloads/downloads.htm). Users select the nozzle to be used in an application, input their operational parameters (spray pressure, nozzle orientation, nozzle orifice, and airspeed) and the models compute the droplet size spectra (volume median diameter, relative span, etc.) that will be produced under these conditions. Users are also provided with a droplet size classification (i.e., medium, coarse, etc.) as specified in the ASABE Standard S572: Spray Nozzle Classification by Droplet Spectra. The atomization nozzles help aerial applicators comply with EPA regulations. These models have greatly impacted the industry; as an example, the State of Arkansas requires that all spray nozzles used in aerial application have a USDA-ARS atomization model prior to use. Given the impact and widespread adoption of these models, our Project continually updates the database with new models for nozzles that gain wide adoption and usage by the industry.

In addition to demonstrating that the Project is responsive to the needs and concerns of the aerial application industry, these accomplishments highlight the need for improved knowledge of the interaction between spray nozzle, operational parameters, physical properties of the spray,

and the atomization process. The new Project will combine each of the fundamental components of the atomization process into a usable, decision support system for applicators, which will lead to better control of the sprays released from an application.

Objective 2: Develop and evaluate systems for aerial delivery of specific pest management materials. A number of projects resulted in optimized application methods and/or delivery systems for a variety of pest control products. Research trials on the development and field testing of an ARS-patented attracticide bait (feeding attractant, feeding stimulant, and insecticide combined) for *Helicoverpa* and other destructive noctuid moths were conducted in cotton fields. Project scientists, in consultation with BioGlobal technical personnel, have tested and defined appropriate ground and aerial application methodologies, formulations, assessment protocols, and techniques for this reduced-toxicant pesticide. Fusarium head blight (FHB), a major disease of wheat and barley, requires targeted and timely applications of fungicides for successful management. Project scientists conducted aircraft spray-deposition trials in Texas, North Dakota, and Minnesota using conventional hydraulic nozzles, electrostatic nozzles, and rotary atomizers. Results indicating that hydraulic nozzles set at the lowest spray rate and largest droplet size along with electrostatic spray nozzles gave maximum spray deposits on wheat heads provide guidance for aerial applicators. Numerous new and traditional pesticides for controlling fleahoppers, thrips, aphids, and plant bugs in corn and cotton were evaluated in laboratory and field trials to determine the influence of application parameters, such as droplet size, spray rate, etc., on product efficacy. The results from these studies were reported to the scientific, application, and farming communities over the last five years.

These accomplishments highlighted the important role that application has on the ultimate success of any crop production or protection chemical. Many of the new pesticides coming onto the U.S. market have significantly lower active ingredient (a.i.) rates than previous conventional pesticides (g/ha versus kg/ha) magnifying the increasing importance of precise delivery to specific locations within the targeted canopy. All three Objectives in the current Project Plan will contribute to a better understanding of the biological impact of new agrochemicals and how to more efficiently deliver these materials within the intended application area at optimal rates.

Objective 3: Develop and integrate technologies for precision application of crop production and protection materials. Variable-rate aerial application methodology was tested on a commercial agricultural aircraft. A Gibsland GA series 200 fixed-wing aircraft equipped with a computer-controlled, variable-rate spraying system was field tested for automated on-off spray capability. Field tests demonstrated that the automated spray system was capable of starting or stopping spraying within 50 feet of the desired location, which relates to 0.25 seconds at normal aerial operating speeds. Additional testing for the variable rate capabilities of the GPS-controlled spraying system using a larger, turbine agricultural aircraft were completed. A rate sequence from 0-5 gpa (gallons per acre), with non-zero target rates of 3, 4, and 5 gpa, was tested with spray deposition collected using water sensitive cards. Results showed that conventional hydraulic nozzles, for which spray rate changes were made by varying spray pressure, could deliver the 3 gpa rate, but were unable to achieve 5 gpa rate at the maximum spray pressure setting. These results indicated that for variable-rate applications over a wide range of spray rates to be practical, dedicated variable rate nozzles are needed.

These accomplishments coupled with very recent studies have shown that despite the increasing interest and potential benefits from integrating GIS data, there are a number of shortcomings in the overall system that first need to be addressed. The acquisition and interpretation of remotely or field-collected GIS requires special training and/or software, which

does not lend itself to on-the-farm use. Remote sensing of agricultural processes and farming conditions are critical to continued high production American agriculture, necessitating that researchers, crop consultants, applicators, and farmers be able to quickly and accurately combine data from multiple sensors to make reliable production decisions. Project scientists are leading the way for the application of multisensor data fusion to precision application and production systems allowing for more accurate application of crop production and protection materials; the current Project Plan addresses many of the critical needs in these areas.

Objective 4: Determine effects of meteorological conditions on efficacy and off-target movement of sprays. Aerial applicators must consider a number of atmospheric conditions and operational factors in assuring that crop protection materials are applied with maximum efficiency. Project scientists conducted aerial field trials under various meteorological and atmospheric stability conditions to define the most critical factors related to on-target deposition and undesired off-target drift. The work showed that while wind speed was the primary factor influencing spray transport and fate, increased atmospheric stability had the effect of maintaining droplet suspension which could potentially increase downwind drift and deposition. This accomplishment provides rigorous scientific data to researchers and aerial applicators to facilitate their efforts to achieve maximum on-target deposition and minimum off-target drift through improvements in drift modeling software and improved recommendations of optimal application conditions.

The AGDISP spray dispersion model is increasingly being used by regulators, aerial applicators, and researchers to understand and predict the impacts of environmental and equipment parameters on spray deposition and movement. Continual validation of the model with data taken in the field is required to make AGDISP even more predictive and valuable to users. Project scientists compared field-collected measurements of aerial spray deposition and airborne movement over six cotton canopies to predictions generated by the AGDISP model. In canopies from 1.0 to 2.5 feet tall, the model effectively predicted actual observations; however, predictive accuracy was less in very dense cotton canopies. This accomplishment further validates the predictive value of AGDISP, increases user confidence, and identifies areas for further improvement.

These accomplishments demonstrate the complexity of environmental and application conditions that must be factored in with each spray application to maximize spray deposition and minimize unintended off-target environmental impact. Each fundamental study conducted over the next five years by this project will serve to build the base of knowledge available to researchers and applicators. It is upon this base that decision support systems will be built to integrate the available scientific data.

Publications Under Prior Project:

2003

Fritz, B. K. 2003. Measurement and analysis of atmospheric stability in two Texas regions. Proc. ASAE/NAAA Tech. Session. Paper No. AA03-005. Reno, NV.

2004

Hoffmann, W. C. and Hewitt, A. J. 2004. Comparison of droplet imaging systems for water-sensitive cards. Aspects Appl. Biol. 71:463-466.

2005

Fritz, B. K., Shaw, B. W. and Parnell, C. B. 2005. Influence of meteorological time frame and variation on horizontal dispersion coefficients in Gaussian dispersion modeling. Trans. ASABE. 48(6):1185-1196.

Fritz, B. K., Hoffmann, W. C. and Martin, D. E. 2005. Aerial application methods for increasing spray deposition on wheat heads. Proc. ASAE/NAAA Tech. Session. Paper No. AA05-006. Reno, NV.

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PAST ACCOMPLISHMENTS OF INVESTIGATORS

Hoffmann, W. Clint

Education

Texas A&M University	Doctor of Philosophy, Agricultural Engineering, 1997
University of Florida	Master of Engineering, Agricultural Engineering, 1994
Texas A&M University	Bachelor of Science, Agricultural Engineering, 1992

Work Experience

2002 – Present	Agricultural Engineer and Lead Scientist, Aerial Application Technology Project, USDA-ARS, College Station, TX
1997 – 2002	Agricultural Engineer, USDA-ARS, College Station, TX
1994 – 1997	Engineering Technician, USDA-ARS, College Station, TX
1992 – 1994	Research Associate, University of Florida, Gainesville, FL

Accomplishments

Over the past three years, $875,000 in additional funds have been brought into the Project in support of the U. S. Department of Defense Deployed War Fighter Protection Program. Work has generated two peer-reviewed articles with three more pending publication.

Conceived and designed testing protocol and apparatus that allowed three laser-based droplet sizing instruments to be operated simultaneously in one wind tunnel.

Developed a spray flux measurement system using monofilament line to accurately and quickly measure spray flux in the field, which allowed comparison of field measured results to computer model predicted results.

Designed, constructed, and tested a spray boom that lowered in flight. The boom lowered approximately 1.8 ft once the aircraft was in flight. The system increased swath width by 12% and reduced the amount of spray drift.

Led the Texas Adult Corn Rootworm Management research program, which was part of the National Areawide Integrated Pest Management Program for Corn Rootworm.

Publications (*indicates publications resulting from previous project)

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Texas A&M University	Doctor of Philosophy, Agricultural Engineering, 2002
Texas A&M University	Master of Engineering, Agricultural Engineering, 1998
Texas A&M University	Bachelor of Science, Agricultural Engineering, 1995

Work Experience

2002 – Present	Agricultural Engineer, USDA-ARS, College Station, TX
2001 – 2002	Research Associate, Texas A&M University, College Station, TX

Accomplishments

Developed dispersion modeling routine for estimating concentrations of particulate downwind from low-level agricultural point sources. As part of this effort, a methodology was developed for estimating time dependent plume spread as a function of monitored meteorological data and atmospheric stability.

Assessed aerial application technologies to optimize spray deposits on wheat heads to effectively control wheat fungal diseases through thorough coverage and deposition of fungicide on wheat heads. Large scale field studies were conducted to examine a number of application technologies for deposition and coverage of wheat heads resulting in aerial application protocols that maximize spray deposits.

A low-speed spray dispersion tunnel was constructed and evaluated for use in sampler collection efficiency studies. Samplers presently used to measure suspended sprays were evaluated for collection efficiency allowing for mass accountability of data collected during spray drift studies.

Publications (*indicates publications resulting from previous project)

Fritz, B. K. 1998. Dispersion modeling of ground-level area sources of particulate. Masters Thesis. Texas A&M University, College Station, TX.

Parnell, C. B., Shaw, B. W. and Fritz, B. K. 1999. Systems engineering, operations research, and management science. In: Stout, B. A. and Cheze, B. (eds.). Handbook of Agricultural Engineering. Vol. III. Plant Production Engineering. American Society of Agricultural Engineers, St. Joseph MI. pp. 521-536.

Fritz, B. K. 2002. Dispersion modeling of particulate emissions from low-level elevated point sources. Ph.D. Dissertation. Texas A&M University, College Station, TX.

*Fritz, B. K. 2003. Measurement and analysis of atmospheric stability in two Texas regions. Proc. ASAE/NAAA Tech. Session. Paper No. AA03-005. Reno, NV.

*Fritz, B. K., Shaw, B. W. and Parnell, C. B. 2005. Influence of meteorological time frame and variation on horizontal dispersion coefficients in Gaussian dispersion modeling. Trans. ASABE. 48(6):1185-1196.

*Witsaman, P. G., Zeitler, J. W., Oaks, M. C., Murdoch, G. P., Nagle, S. R., Hoffmann, W. C. and Fritz, B. K. 2005. HI-RISE - Hazardous incident rapid in-flight support effort: Use of

asynoptic upper-air data to improve weather forecasts at wildland fires and other hazardous incidents. Proc. Joint 6th Symp. on Fire and Forest Meteorology/19th Interior West Fire Council Meet. Canmore, Alberta, Canada. CDROM.

*Fritz, B. K., Hoffmann, W. C. and Martin, D. E. 2005. Aerial application methods for increasing spray deposition on wheat heads. Proc. Nat Agric. Aviat. Assoc. Meet, Paper No. AA05-006. Reno, NV.

*Fritz, B. K., Kirk, I. W., Hoffmann, W. C., Martin, D. E., Hofman, V., Hollingsworth, C., McMullen, M. and Halley, S. 2006. Aerial application methods for increasing spray deposition on wheat heads. Appl. Eng. Agric. 22:357-364.

*Fritz, B. K. 2006. Meteorological effects on deposition and drift of aerially applied sprays. Trans. ASABE. 49:1295-1301.

*Fritz, B. K. 2006. Atmospheric and stability effects on aerially applied agricultural sprays-preliminary results. Proc. Nat. Agric. Aviat. Assoc. Nat. Meet. Paper No. AA06-006. Orlando, FL.

*Lan, Y., Hoffmann, W. C., Fritz, B. K., Martin, D. E. and López, J. 2006. Effectiveness of spray adjuvants on reduction of spray drift. Proc. ASABE. Paper No. AA06-004. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

*Hoffmann, W. C., Fritz, B. K. and Martin, D. E. 2007. AgDISP sensitivity to crop canopy characterization. Trans. ASABE. 50:1117-1122.

*Hoffmann, W. C., Walker, T. W., Smith, V. L, Martin, D. E. and Fritz, B. K. 2007. Droplet-size characterization of handheld atomization equipment typically used in vector control. J. Am. Mosq. Contr. Assoc. 23(3):312-314.

*Hoffmann, W. C., Walker, T. W., Martin, D. E., Barber, J. A. B., Gwinn, T., Smith, V. L., Szumlas, D., Lan, Y. and Fritz, B. K. 2007. Characterization of truck-mounted atomization equipment used in vector control. J. Am. Mosq. Contr. Assoc. 23(3):315-320.

*Fritz, B. K., Hoffmann, W. C., Martin, D. E. and Thomson, S. J. 2007. Aerial application methods for increasing spray deposition in wheat heads. Appl. Eng. Agric. 23(6):709-715.

*Hoffmann, W. C., Bagley, W. E., Fritz, B. K., Lan, Y. and Martin, D. E. 2008. Effects of water hardness on spray droplet size under aerial application conditions. Appl. Eng. Agric. 24(1):11-14.

*Fritz, B. K. and Hoffmann, W. C. 2008. Collection efficiency of airborne spray flux samplers. J. ASTM Int. 5(1):1-10.

*Fritz, B. K. and Hoffmann, W. C. 2008. Development of a system for determining collection efficiency of spray samplers. Appl. Eng. Agric. (Accepted Jan. 2008)

Yubin Lan

Education

Texas A&M University	Doctor of Philosophy, Agricultural Engineering, 1994
Jilin University	Master of Science, Agricultural Engineering, 1987
Jilin University	Bachelor of Science, Agricultural Engineering, 1982

Work Experience

2005 – Present	Agricultural Engineer, Aerial Application Technology Project, USDA-ARS, College Station, TX
2003 – 2005	Associate Professor, Fort Valley State University, Fort Valley, GA
1999 – 2003	Assistant Professor, Fort Valley State University, Fort Valley, GA
1995 – 1999	Research/Control Engineer, University of Nebraska, Lincoln, NE
1993 – 1995	Postdoctoral Research Associate, TAES, Corpus Christi, TX

Accomplishments

Designed a sorting machine for rice grains, a threshing machine, and a small combine.

Developed a new processing procedure to minimize rice fissures.

Developed crop management strategies using ICEMM of Crop-Insect-Weather-Economics Scenarios.

Developed, constructed, and tested an opto-electronic sensor system for measurement of plant seed spacing.

Conceived and used biosensor and electronic nose technology to detect bacteria in meat.

Conceived and designed a low-current electricity system with the help of electrolyte solutions to kill *E. coli* O157:H7 on meat surfaces.

Developed a protocol for testing effectiveness of spray adjuvants on drift reduction.

Conceived and tested an aerial imaging system for crop pest management.

Publications (*indicates publications resulting from previous project)

Lan, Y. and Kunze, O. R. 1996. Fissure characteristics related to moisture adsorption stresses in rice. Trans. ASAE. 39(6):2169-2174.

Kocher, M., Lan, Y., Chen, C. and Smith, J. 1997. Opto-electronic sensor system for rapid evaluation of planter seed spacing uniformity. Trans. ASAE. 41(1):237-245.

Lan, Y., Kocher, M. and Smith, J. 1999. Opto-electronic sensor system for laboratory measurement of planter seed spacing with small seeds. J. Agric. Eng. Res. 72:119-127.

Lan, Y., Kunze, O. R., Lague, C. and Kocher, M. F. 1999. Mathematical model of the distribution of stress within a rice kernel from moisture adsorption. J. Agric. Eng. Res. 72:247-257.

Lan, Y., Fang, Q. Kocher, M. F. and Hanna, M. 2002. Detection of fissures in rice grains using imaging enhancement. Int. J. Food Prop. 5(1):205-215.

Wang, D., Dowell, F. E., Lan, Y., Pasikatan, M. and Maghirang, E. 2002. Determining pecky rice kernels using visible and near-infrared spectroscopy. Int. J. Food Prop. 5(3):629-639.

Saif, S. M. H., Lan, Y., Wang, S. and Garcia, S. 2004. Electrical resistivity of goat meat. Int. J. Food Prop. 7(3):463-471.

Huang, Y., Lan, Y. and Lacey, R. 2004. Artificial senses for characterization of food quality. J. Bionics Eng. 1(3):159-173.

Saif, S., Lan, Y., Williams, L., Joshee, L. and Wang, S. 2006. Reduction of *Escherichia coli* O157:H7 on goat meat surface with pulsed dc square wave signal. J. Food Eng. 77: 281-288.

*Lan, Y., Benedict, J. H., Ring, D. R. and Hoffmann, W. C. 2006. Economic analysis of insect control strategies using an integrated crop ecosystem management model. Agric. Eng. Int.: CIGR Ejournal. 8:1-18.

*Huang, Y., Lan, Y., Hoffmann, W. C. and Lacey, R. 2007. Multisensor data fusion for high quality data analysis and processing in measurement and instrumentation. J. Bionics Eng. 6 (1):53-62.

*Lan, Y., Lin, X., Kocher, M. F. and Hoffmann, W. C. 2007. Development of a PC-based data acquisition and control system. Agric. Eng. Int.: CIGR Ejournal. 9:1-11.

*Zhang, S., Lan, Y., Li, W., Xu, Y., Hoffmann, W. C. and Ma, C. 2007. Variable rate fertilization for maize and its effects based on the site-specific soil fertility and yield goal. Proc. ASABE. Paper No. 07-1066. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

Zhu, H., Lan, Y., Lamb, M. C. and Butts, C. L. 2007. Corn nutritional properties and yields with surface drip irrigation in topographically variable fields. Agric. Eng. Int.: CIGR Ejournal. 9:1-10.

*Zhang, S., Lan, Y., Wu, W., Hoffmann, W. C. and Chen, G. 2007. Development of a data acquisition and processing system for precision agriculture. Proc. ASABE. Paper No. 07-1067. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

*Lan, Y., Hoffmann, W. C., Westbrook, J. and Huang, Y. 2007. Development of a precision areawide pest management decision system for cotton-preliminary study. Proc. 4th World Cotton Research Conference. Lubbock, TX.

*Lan, Y., Huang, Y., Martin, D. E. and Hoffmann, W. C. 2007. Crop pest management with an aerial imaging system. Proc. NAAA-ASABE. Paper #AA07-005. Reno, NV.

*Hoffmann, W. C., Bagley, W. E., Fritz, B. K., Lan, Y. and Martin, D. E. 2008. Effects of water hardness on spray droplet size under aerial application conditions. Appl. Eng. Agric. 24(1):11-14.

*Lan, Y., Hoffmann, W. C., Fritz, B. K., Martin, D. E. and López, J. D. 2008. Spray drift mitigation with spray mix adjuvants. Appl. Eng Agric. 24(1):5-10.

*Huang, Y., Lan, Y., Westbrook, J. and Hoffmann, W. C. 2008. Remote sensing and GIS applications for precision areawide pest management. Implications for homeland security. In: Sui, D. Z. and Cutter, S. L. (eds.). Geospatial Technologies and Homeland Security: Research Frontiers and Challenges. Springer, New York. (Book Chapter; Accepted Aug. 2007)

Juan D. López, Jr.

Education

Texas A&M University	Doctor of Philosophy, Entomology, 1976
Texas A&M University	Master of Science, Entomology, 1973
Texas A&M University	Bachelor of Science, Entomology, 1968

Work Experience

1991 – Present	Research Entomologist, Areawide Pest Management Research Unit, USDA-ARS, College Station, TX
1989 – 1991	Supervisory Research Entomologist and Lead Scientist, Aerial Application Research Unit, USDA-ARS, College Station, TX
1984 – 1989	Supervisory Research Entomologist and Research Leader, Cotton Insects Research Laboratory, College Station, TX
1976 – 1984	Research Entomologist, USDA-ARS, College Station, TX
1972 – 1976	Research Fellow and Research Assistant, Department of Entomology, Texas A&M University, College Station, TX
1969 – 1972	Military Entomologist, U.S. Army, Fort Sam Houston, San Antonio, TX and 5th Preventive Medicine Unit, Pusan, Korea
1968 – 1969	Research Fellow, Department of Entomology, Texas A&M University, College Station, TX

Accomplishments

Developed and evaluated sex pheromone trapping technology for monitoring corn earworm/ bollworm, tobacco budworm, beet armyworm, and other lepidopteran insect pests. Based on studies of overwintering/diapause and seasonal patterns of capture in pheromone traps, contributed to a detailed understanding of the population dynamics of corn earworm/bollworm and tobacco budworm on various host plants in the Brazos River Valley of Texas, and recognition of the importance of long distance migration in the population dynamics of corn earworm/bollworm.

Evaluated numerous aspects of the biology and behavior of predators and parasitoids relative to use in conserving and augmenting biological control agents of cotton insect pests.

Developed and evaluated adult control technology for noctuid moths with special emphasis on corn earworm/bollworm using feeding attractants and stimulants in mixtures with insecticides which led to a senior-authored patent on feeding attractants, CRADAs with various companies involved in insect pest control internationally, and development of a practical field formulation that can be applied aerially. This formulation has the potential of controlling noctuid pests by treating as little as 2% of the crop area.

Used a computer-controlled spray table that simulated aerial application of insecticides for assessment of deposition characteristics; and bioassay of efficacy in controlling thrips, cotton aphids, cotton fleahoppers, and stink bugs on cotton plants. Results of insecticide efficacy obtained from the spray table were validated under field conditions using aerial application.

Publications (*indicates publications resulting from previous project)

López, J. D., Jr., Ridgway, R. L. and Pinnell, R. E. 1976. Comparative efficacy of four insect predators of the bollworm and tobacco budworm. Environ. Entomol. 5(6):1160-1164.

López, J. D., Jr., Hartstack, A. W., Jr., Witz, J. A. and Hollingsworth, J. P. 1978. *Heliothis zea*: Oviposition on corn and sorghum in relation to host phenology. Southwest. Entomol. 3(2):158-165.

López, J. D., Jr., Hartstack, A. W., Jr., Witz, J. A. and Hollingsworth, J. P. 1979. Relationship between bollworm oviposition and moth catches in blacklight traps. Environ. Entomol. 8(1):42-45.

López, J. D., Jr. and Morrison, R. K. 1980. Susceptibility of immature *Trichogramma pretiosum* to freezing and sub-freezing temperatures. Environ. Entomol. 9(5):697-700.

López, J. D., Jr., Shaver, T. N. and Hartstack, A. W., Jr. 1981. Evaluation of dispensers for the pheromone of *Heliothis zea*. Southwest. Entomol. 6(2):117-122.

López, J. D., Jr., Hartstack, A. W., Jr. and Beach, R. 1984. Comparative pattern of emergence of *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae) from overwintering pupae. J. Econ. Entomol. 77(6):1421-1426.

López, J. D., Jr. and Hartstack, A. W., Jr. 1985. Comparison of diapause development in *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Am. 78(3):415-422.

López, J. D., Jr. and Witz, J. A. 1988. Influence of *Heliothis virescens* sex pheromone dispensers on captures of *H. zea* males in pheromone traps relative to distance and wind direction. J. Chem. Ecol. 14(1):265-276.

López, J. D., Jr., Shaver, T. N. and Dickerson, W. A. 1989. Population monitoring of *Heliothis* spp. with pheromones. In: Ridgway, R. L., Silverstein, R. M. and Inscoe, M. (eds.). Behavior-Modifying Chemicals for Insect Management. Marcel Dekker, Inc., New York. pp. 473-496.

López, J. D., Jr. and Shaver, T. N. 1990. Plastic laminate dispenser for components of the *Heliothis zea* sex pheromone. Southwest. Entomol. 15(1):1-8.

López, J. D., Jr., Goodenough, J. L. and Beerwinkle, K. R. 1994. Comparison of two-sex pheromone trap designs for monitoring corn earworm and tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 87(3):791-801.

López, J. D., Jr. and Lingren, P. D. 1994. Feeding response of adult *Helicoverpa zea* (Lepidoptera: Noctuidae) to commercial phagostimulants. J. Econ. Entomol. 87(6):1653-1658.

López, J. D., Jr., Beerwinkle, K. R., Witz, J. A. and Goodenough, J. L. 1995. Spatial and temporal patterns of catches in pheromone traps of *Helicoverpa zea* and *Heliothis virescens* in Central Texas. In: Raulston, J. R. and Slosser, J. E. (eds.). Noctuids: Recent Advances in Detection and Migration in the United States. Southwest. Entomol. Suppl. 18:5-24.

López, J. D., Jr., Sterling, W. L., Dean, D. A. and Nordlund, D. A. 1996. Biology and ecology of important predators and parasites attacking arthropod pests. In: King, E. G., Phillips, J.

R. and Coleman, R. J. (eds.). Cotton Insects and Mites: Characterization and Management. No. III. The Cotton Foundation Reference Book Series. pp. 87-142.

López, J. D., Jr., Shaver, T. N., Beerwinkle, K. R. and Lingren, P. D. 2000. Feeding attractant and stimulant for adult control of noctuid and/or other lepidopteran species. U.S. Patent No. 6,074,634.

López, J. D., Jr., Crocker, R. L. and Shaver, T. N. 2002. Attractant for monitoring and control of adult scarabs. U.S. Patent No. 6,440,406.

Prom, L. K. and López, J. D., Jr. 2004. Viability of *Claviceps africana* spores ingested by adult corn earworm moths, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae). J. Econ. Entomol. 7(3):764-767.

*Martin, D. E., López, J. D., Jr., Hoffmann, W. C., Fritz, B. K. and Lan, Y. 2007. Field evaluation of Spinosad aerial application for thrips control on cotton. Southwest. Entomol. 32(4):221-228.

*Lan, Y., Hoffmann, W. C., Fritz, B. K., Martin, D. E. and López, J. D., Jr. 2008. Spray drift mitigation with spray mix adjuvants. Appl. Eng. Agric. 24(1):1-7.

*Martin, D. E., López, J. D., Jr., Fritz, B. K., Lan, Y., Hoffmann, W. C. and Duke, S. E. 2008. Novaluron as an ovicide for bollworm on cotton: Deposition and efficacy of field-scale aerial applications. J. Cotton Sci. (Accepted Nov. 2007)

Martin, Daniel E.

Education

Louisiana State University	Doctor of Philosophy, Engineering Science, 2003
Louisiana State University	Master of Science, Agricultural Engineering, 1994
Virginia Tech	Bachelor of Science, Agricultural Engineering, 1988

Work Experience

2004 – Present	Research Engineer, Aerial Application Technology Project, USDA-ARS, College Station, TX
1994 – 2004	Extension Associate, Louisiana State University, Baton Rouge, LA
1989 – 1994	Research Associate, Louisiana State University, Baton Rouge, LA

Accomplishments

Determined optimum processing parameters for stabilizing rice bran from oxidation and hydrolysis *via* extrusion and identified significant differences in proximate composition (moisture, oil, crude fiber, protein, ash) and storage quality (thiobarbituric acid value and free fatty acid content) between rice varieties and types which resulted in the development of rapid, non-chemical rice bran quality determination methods.

Developed a low-cost process to automatically shuck oysters with a low-temperature steam system that preserved taste, reduced bacteria, and increased the shelf-life of oysters.

Demonstrated that novaluron (Diamond 0.83EC®), a relatively new insect growth regulator with ovicidal activity, increased bollworm egg and larval mortality as compared to methomyl (Lannate LV®), the industry standard. The work showed that novaluron can be aerially applied and that it provides better efficacy than conventional insecticides. Because of the now field-proven ovicidal activity of novaluron, it will likely be used extensively to control tolerant or resistant cotton bollworm/budworm, which will enhance crop production efficiency and reduce adverse environmental impacts given its mode of action.

Demonstrated that spinosad (Tracer®), a naturally-derived insecticide, showed superior performance in deposition and efficacy compared to the standard for control of thrips in cotton. This study showed that novel chemical technologies, with lower toxicity to humans and beneficial insects, can be applied at lower application rates with equal or better efficacy. Use of spinosad, being very environmentally-friendly and labeled for organic production, is a powerful tool for thrips control in crop production *via* aerial application. The ability of aerial applicators to apply materials at lower volumes will allow an increase in operational efficiency with a significant reduction in fuel consumption.

Publications (*indicates publications resulting from previous project)

Martin, D. E. 1993. Fungi contribute to rice bran stability. La. Agric. 36:20.

Martin, D. E., Godber, J. S., Setlhako, G. O., Verma, L. R. and Wells, J. H. 1993. Optimizing rice bran stabilization by extrusion cooking. La. Agric. 36:13-15.

Godber, J. S., Martin, D. E., Shin, T. S., Setlhako, G. O., Tricon, C. and Gervais, M. 1993. Quality parameters important in rice bran for human consumption. La. Agric. 36:9-12.

Martin, D. E. 1994. Extrusion stabilization and near-infrared analysis of rice bran. Masters Thesis. Louisiana State University, Baton Rouge.

Shin, T. S., Godber, J. S., Martin, D. E. and Wells, J. H. 1997. Hydrolytic stability and changes in E vitamers and oryzanol of extruded rice bran during storage. J. Food Sci. 62:704-708.

*Fritz, B. K., Kirk, I. W., Hoffmann, W. C., Martin, D. E., Hofman, V., Hollingsworth, C., McMullen, M. and Halley, S. 2006. Aerial application methods for increasing spray deposition on wheat heads. Appl. Eng. Agric. 22(3):357-364.

Martin, D. E. and Hall, S. G. 2006. Oyster shucking technologies: Past and present. Int. J. Food Sci. Tech. 41:223-232.

*Hoffmann, W. C., Walker, T. W., Smith, V. L, Martin, D. E. and Fritz, B. K. 2007. Droplet-size characterization of handheld atomization equipment typically used in vector control. J. Am. Mosq. Contr. Assoc. 23(3):312-314.

*Hoffmann, W. C., Walker, T. W., Martin, D. E., Barber, J. A. B., Gwinn, T., Smith, V. L., Szumlas, D., Lan, Y. and Fritz, B. K. 2007. Characterization of truck-mounted atomization equipment used in vector control. J. Am. Mosq. Contr. Assoc. 23(3):315-320.

*Fritz, B. K., Hoffmann, W. C., Martin, D. E. and Thomson, S. J. 2007. Aerial application methods for increasing spray deposition in wheat heads. Appl. Eng. Agric. 23(6):709-715.

*Hoffmann, W.C., Fritz, B. K. and Martin, D. E. 2007. AgDISP sensitivity to crop canopy characterization. Trans. ASABE. 50(6):1117-1122.

Martin, D. E., Supan, J., Theriot, J. and Hall, S. G. 2007. Development and testing of a heat-cool methodology to automate oyster shucking. J. Aquacult. Eng. 37(1):53-60.

Martin, D. E. and Hall, S. G. 2007. Effectiveness of a heat/cool technique for shucking oysters. J. Aquacult. Eng. 37(1):61-66.

*Martin, D. E., López, J. D., Jr., Hoffmann, W. C., Fritz, B. K. and Lan, Y. 2007. Field evaluation of Spinosad aerial application for thrips control on cotton. Southwest. Entomol. 32(4):221-228.

*Hoffmann, W. C., Bagley, W. E., Fritz, B. K., Lan, Y. and Martin, D. E. 2008. Effects of water hardness on spray droplet size under aerial application conditions. Appl. Eng. Agric. 24(1):11-14.

*Martin, D. E., López, J. D., Jr., Fritz, B. K., Lan, Y., Hoffmann, W. C. and Duke, S. E. 2008. Novaluron as an ovicide for bollworm on cotton: Deposition and efficacy of field-scale aerial applications. J. Cotton Sci. (Accepted Nov. 2007)

Westbrook, John K.

Education

Utah State University	Doctor of Philosophy, Biometeorology, 1982
Utah State University	Master of Science, Biometeorology, 1980
San Jose State University	Bachelor of Science, Meteorology, 1977
Sierra College	Associate of Arts, Mathematics, 1975

Work Experience

1999-Present	Meteorologist and Research Leader, USDA-ARS, Areawide Pest Management Research Unit, College Station, TX
1991-Present	Meteorologist, USDA-ARS, Southern Plains Agricultural Research Center, Areawide Pest Management Research Unit, College Station, TX
1982-1991	Meteorologist, USDA-ARS, Insect Biology & Population Management Research Laboratory, Insect Migration/Dispersal Research Unit, Tifton, GA
1982	Postdoctoral Research Meteorologist, University of Georgia, Dry Branch, GA
1977-1982	Graduate Research Assistant, Dept. of Soil Science and Biometeorology, Utah State University, Logan, UT, and Inst. of Mechanical Turbulence, Swiss Inst. of Technology, Lausanne, Switzerland

Accomplishments

Identified temporal patterns of exodus flight activity, altitudinal distribution, and collective orientation of migrating bollworms relative to wind velocity and temperature distributions.

Developed weather balloon tracking instrumentation and pioneered the use of superpressure balloons for insect migration research, which helped to validate predictions of long-distance migratory flights of bollworms in the south-central U.S.

Identified warm precipitation events associated with episodes of peak spring emergence of overwintered boll weevils.

Identified patterns of areawide production and flight activity of bollworms and other Lepidopteran crop pests relative to feeding flights by insectivorous Brazilian free-tailed bats.

Publications (*indicates publications resulting from previous project)

Westbrook, J. K., Raulston, J. R., Wolf, W. W., Pair, S. D., Eyster, R. S. and Lingren, P. D. 1995. Field observations and simulations of atmospheric transport of noctuids from northeastern Mexico and the south-central U.S. Southwest. Entomol. Suppl. 18:25-44.

Westbrook, J. K., Eyster, R. S., Wolf, W. W., Lingren, P. D. and Raulston, J. R. 1995. Migration pathways of corn earworm indicated by tetroon trajectories. Agric. Forest Meterol. 73:67-87.

Westbrook, J. K., Wolf, W. W., Lingren, P. D., Raulston, J. R., López, J. D., Jr., Matis, J. H., Eyster, R. S., Esquivel, J. F. and Schleider, P. G. 1997. Early-season migratory flights of corn earworm (Lepidoptera: Noctuidae). Environ. Entomol. 26:12-20.

Westbrook, J. K. and Lingren, P. D. 1998. Meteorology and strategies for using plant attractants in adult suppression programs. Southwest. Entomol. 21:47-58.

Westbrook, J. K., Esquivel, J. F., López, J. D., Jr., Wolf, W. W. and Raulston, J. R. 1998. Validation of bollworm migration across south-central Texas in 1994-1996. Southwest. Entomol. 23:209-219.

Westbrook, J. K. and Isard, S. A. 1999. Atmospheric scales of biotic dispersal. Agric. Forest Meterol. 97:263-274.

Patterson, D. T., Westbrook, J. K., Joyce, R. G. V., Lingren, P. D. and Rogasik, J. 1999. Weeds, insects and diseases. Clim. Change. 43:711-727.

Eiceman, G. A., Tadjikov, B., Krylov, E., Nazarov, E. G., Miller, R. A., Westbrook, J. and Funk, P. 2001. Miniature radio-frequency mobility analyzer as a gas chromatographic detector for oxygen-containing volatile organic compounds, pheromones and other insect attractants. J. Chromatog. A. 917:205-217.

Luo, L., Johnson, S. J., Hammond, A. M., López, J. D., Geaghan, J. P., Beerwinkle, K. R. and Westbrook, J. K. 2002. Determination and consideration of flight potential in a laboratory population of true armyworm (Lepidoptera: Noctuidae). Environ. Entomol. 31:1-9.

Suh, C.P.-C., Spurgeon, D. W. and Westbrook, J. K. 2002. Influence of feeding status and physiological condition on supercooling points of adult boll weevils (Coleoptera: Curculionidae). Environ. Entomol. 31:754-758.

McCracken, G. F. and Westbrook, J. K. 2002. Bat patrol. National Geographic. 201(4):114-123.

Westbrook, J. K., Spurgeon, D. W., Eyster, R. S. and Schleider, P. G. 2003. Emergence of overwintered boll weevils (Coleoptera: Curculionidae) in relation to microclimatic factors. Environ. Entomol. 32:133-140.

James, W. E., Showler, A. T., Westbrook, J. K. and Armstrong, J. S. 2006. Stable isotope tracer marking of individual boll weevils. J. Radioanalyt. Nuc. Chem. 269(2):267-270.

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Issues of Concern

Animal Care - This research does not involve work with animals.

Endangered Species - This research does not involve work with endangered species, and its outcome will have no negative impact on any endangered species.

National Environmental Policy Act - This research project has been examined for potential impacts on the environment and has been found to be categorically excluded under ARS regulations from the National Environmental Policy Act.

Human Study Procedures - This research does not involve work with human subjects.

Laboratory Hazards - All hazardous materials will be handled with appropriate protective clothing and, as required or as appropriate, used in fume hoods.

Occupational Safety and Health - This research involves working with agricultural chemicals; accordingly, annual medical examinations are provided to all staff members. Safety courses, training, and protective clothing and equipment are provided as needed.

Recombinant DNA Procedures - This research does not involve work with recombinant DNA.

Homeland Security - Due to the high visibility and security concerns associated with aerial application and particularly agricultural aircraft, all personnel involved with this project must remain vigilant when discussing aerial application issues with persons who are unknown to the individual. Any person who expresses a keen interest in specific aspects relating to the operation of aerial application equipment or aircraft should be reported to the Lead Scientist, Research Leader, or law enforcement personnel. All project personnel have been provided a copy of ARS DM9610-002 “USDA Security Policies and Procedures.”

Intellectual Property Issues - All researchers in this project are aware of the importance of securing intellectual property and have been provided copies of the ARS Bulletin on Intellectual Property. At this time, no potential intellectual property issues with collaborators or other researchers are expected.

Existing Specific Cooperative Agreements - There are no SCAs relevant to this project.

While preparing the Project Plan, I (W. C. Hoffmann) have carefully examined all aspects of the planned research to ensure that appropriate safety concerns are addressed, all necessary permits have been identified, and that environmental issues have been considered in making the National Environmental Policy Act (NEPA) decision documented in the statement. All permits are in hand or have been requested. Documentation supporting NEPA decision is in the MU project file and available for review upon request.

I (James R. Coppedge) certify that the proposed research conforms to current regulations and guidelines regarding the above issues and concerns.

/s/ James R. Coppedge 4/21/2008
James R. Coppedge, Associate Area Director Date

Appendix 1: Letters of Collaboration

USDA

United States Department of Agriculture

Agricultural Research Service

Midsouth Area
Application and Production Technology Research Unit
141 Experiment Station Rd
Stoneville, MS 38776

29 February 2008

Daniel E. Martin, Ph.D.
Research Engineer
Aerial Application Technology Research
USDA-ARS APMRU
2771 F&B Road
College Station, TX 77845

Dear Dr. Martin:

The purpose of this letter is to confirm my intention to collaborate with you and the other scientists with ARS in the APMRU, College Station, TX on several projects over the next five years. I have already been actively involved with your group for the past several years and look forward to continuing this relationship. Specifically, I will contribute the following expertise:

- Selection of equipment and development of methods for rapidly acquiring remotely sensed data (ground-based and/or aerial), geo-referencing aerial images, converting geospatial data into useful vegetation indices, and creating prescription maps for variable-rate aerial application.

- Design and testing of a variable-rate aerial application system. This work will include selection and testing of components integral to a variable-rate system, seeking to automate the system for transparency to the pilot. I will utilize expertise gained from dynamic testing of Global Positioning Systems used to augment variable flow control and guidance for agricultural aircraft. I further believe this collaboration will be highly beneficial to the aerial application industry as our combined talents will be required for this challenging task to be successful.

Sincerely,

Steven J. Thomson, Ph.D.
USDA-ARS-APTRU
141 Experiment Station Rd
Stoneville, MS 38776

Office: (662) 686-5240 Cell: (662) 822-9424 Email: steve.thomson@ars.usda.gov

DEPARTMENT OF THE NAVY
NAVY ENTOMOLOGY CENTER OF EXCELLENCE
P.O. BOX 43, NAVAL AIR STATION
JACKSONVILLE, FL 32212-0043

6250
Ser 06/03389
23 Jan 08

From: Officer In Charge, Navy Entomology Center of Excellence
To: Director, U.S. Department of Agriculture, Agricultural Research Service (ARS), Areawide Pest Management Research Unit (Attn: Dr. W. Clint Hoffman), 2771 F&B Road, College Station, TX 77845

Subj: SPECIAL PROJECT COLLABORATION

1. The purpose of this letter is to confirm our intentions to collaborate with Dr. Clint Hoffman and other scientists with ARS in College Station, Texas on several projects over the next five years. We have been actively involved with Dr. Hoffman and ARS for the last three years and look forward to continuing this very productive relationship. The specific projects that we will work together on are:

a. Field testing of the Unmanned Aerial Vehicle (UAV) spray system: These studies will involve field trials to determine the functionality of the UAV spray system related to effective swath width, droplet size generation, and/or biological efficacy.

b. Sprayer evaluation studies: Sprayers used for controlling arthropod vectors of human and animal diseases will be evaluated in terms of spray droplet size produced at varying rates and with different products.

c. Field assessments of sprayers used for vector control: These studies will focus on evaluating the movement of sprays and/or spray deposition on foliage under vector control situations.

2. For each of these research projects, we will provide equipment, technical expertise, and other resources as needed to complete the projects. All of these studies are being conducted to support the U.S. military's Deployed Warfighter Protection Program.

3. My point of contact for this matter is Dr. Todd W. Walker. He may be reached at (904) 542-2424, extension 3028, or email: todd.walker@navy.mil.

TEXAS A&M UNIVERSITY
Biological and Agricultural Engineering Department

January 7, 2008

Dr. Yubin Lan, Agricultural Engineer
USDA-ARS-APMRU
2771 F & B Road
College Station, TX 77845

Dear Dr. Lan:

Thank you for the invitation to collaborate with you on your research projects in developing a remote sensing system for precision agriculture, developing sensors that measure crop conditions, and developing and implementing crop growth and management decision systems in order to optimize aerial applications of agrochemicals.

My research interests in applications of remote sensing and in sensor and controls development are consistent with your research and I hope to provide additional expertise and experience to your efforts. Additionally, I anticipate that personnel support through graduate students and visiting scholars will be available to work on your projects.

Sincerely,
Ronald E. Lacey, P.E., PhD.
Professor
Associate Director, Center for Agricultural Air Quality Engineering and Science

201 Scoates Hall • 2117 TAMU • College Station, Texas 77843-2117 • Voice (979) 845-3021 FAX (979) 862-3442
http://www.bae.tamu.edu/

United States Department of Agriculture
Research, Education and Economics
Agricultural Research Service

2/6/2008

TO: Drs. Wesley Hoffmann, Bradley Fritz, Yubin Lan, Juan Lopez, Daniel Martin
USDA/ARS Aerial Application Technology Research Unit
2771 F&B Road
College Station, TX 77845

FROM: Dr. Heping Zhu
USDA/ARS Application Technology Research Unit
1680 Madison Ave.
Wooster, OH 44691

This letter is to confirm my intent to collaborate with you all, the ARS scientists in the APMRU at College Station, Texas on a number of projects over the next five year period. Our ATRU has a strong history of cooperative effort with members of the APMRU to advance pesticide spray application technologies. I am looking forward to continuing our joint research relationships.

For your projects "Develop and implement standard procedures for evaluating drift reduction technologies and assessing biological impacts of sprays in crop canopies", we will provide you our data for ground spray applications collected in nursery fields, also the assessment of droplet size spectra for various ground delivery systems. The ATRU has developed techniques on measurement air velocities in turbulent conditions, sampling methods and devices including air and ground level samplers and concurrent microclimate monitoring systems. The ATRU has also done initial coverage and drift research in nurseries, applying methods developed in earlier orchard research, and developed databases, models and modeling methods to estimate drift potentials for field spraying operations as used in field row crops.

We will also offer our entomological cooperation in development and test of your electronic sensors to detect volatile organic compounds associated with insect pest infestations and pesticide applications in the nursery environment, joint research to identify efficient and effective aerial and ground spray application techniques for controlling soybean insects and diseases.

Sincerely,

Heping Zhu

Midwest Area • Application Technology Research Unit
1680 Madison Avenue • Wooster, OH 44691
Voice: (330) 263-3771 • FAX: (330) 263-3553 • Email: heping.zhu@ars.usda.gov

中国农业大学资源与环境学院

COLLEGE OF RESOURCES AND ENVIRONMENTAL SCIENCES, CHINA AGRICULTURAL UNIVERSITY

October 9, 2007

Dr. Yubin Lan, Agricultural Engineer
USDA-ARS-APMRU
2771 F & B Road
College Station, TX 77845
USA

Dear Dr. Lan:

Thank you for the invitation for me to work as a collaborator on your research projects in developing sensors that measure crop conditions, applying remote sensing technologies for crop pest management, and developing and implementing crop growth and management decision systems into aerial applications spray optimization. I am very happy to collaborate with you in these and other related projects on precision agriculture and resource management.

When I worked as a Master student in West Texas A&M University, I worked on characterizing soil spatial variability in both crop and rangeland. When I worked as a Ph.D. student in University of Minnesota, I worked on evaluating different precision crop management strategies to optimize both corn yield and grain quality parameters in close collaboration with three agricultural companies (Mosaic, Cargill Dry Corn Ingredients and Pioneer Hi-Bred International). When I worked as a Postdoctoral Research Associate at the Precision Agriculture Center of University of Minnesota, I worked on remote sensing-based precision nitrogen management of corn, involving aerial hyperspectral remote sensing, CropScan multispectral radiometer, GreenSeeker and SPAD meter. Currently, I am working as an associate professor in Department of Plant Nutrition, College of Resources and Environmental Sciences, China Agricultural University (CAU) in Beijing, China. My research is focusing on applying and developing sensing technologies and other information technologies for precision crop management under both large and small scale farming conditions.

When you and Dr. W. Clint Hoffmann visited our university in July 2007, we already had a good discussion for our common interests in collaborating research projects in precision agriculture. I am glad to see these discussions have turned out to be fruitful. Our administrators at CAU strongly support our collaborations, which, I believe, will be fruitful and mutual beneficial. Thank you very much and look forward to working together with you!

Sincerely,

Yuxin Miao

Dr. Yuxin Miao, Associate Professor
Precision Agriculture & Nutrient Management
Department of Plant Nutrition
College of Resources and Environmental Sciences
China Agricultural University
Tel: 86-10-62732865
Email: ymiao@cau.edu.cn

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吉林大学

Dr. Professor Jin TONG
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Jilin University, Nanling Campus
5988 Renmin Street, 130025 Changchun
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Tel: +86-431-85095730
Fax: +86-431-85095255
E-mail: jtong@jlu.edu.cn

JILIN UNIVERSITY·CHINA 1946

October 8, 2007

Dr. Yubin Lan, Agricultural Engineer
USDA-ARS-APMRU
2771 F & B Road
College Station, TX 77845
USA

Dear Dr. Lan:

When you and Dr. W. Clint Hoffmann visited our college in July 2007, we had a good discussion for our potential collaborations in research projects such as sensor and controls development. This letter is written to confirm our agreement for this collaboration with your research projects in 2008 to 2013.

My colleagues and I have experience in developing electronic nose system before. We also have 3 professors who are working in precision agriculture. One of them, Dr. Shuhui Zhang, is working as a visiting scholar in your lab now. Dr. Wenfu Wu in our college will go to your lab in March 2008 to work with you for a couple of months. I and other 3 professors will have opportunity to visit your lab in May 2008.

I am glad to see your and Dr. Hoffmann's visitation strengthening our collaborations. Our administrators at Jilin University also support our collaborations. Thank you.

Sincerely,

Dr. Jin Tong, Professor and Dean
College of Biological and Agricultural Engineering
Jilin University, Renmin Steet 130025
P.R. China
Tel: 186-431-85095730
Email: jtong@jlu.edu.cn

中国科学院遥感应用研究所

October 8, 2007

Dr. Yubin Lan, Agricultural Engineer
USDA-ARS-APMRU
2771 F & B Road
College Station, TX 77845
USA

Dear Dr. Lan:

This letter is written to conform that we agree to work with you as a collaborator on your research project in developing and optimizing the use of unmanned autonomous aerial vehicles (UAV) for pest control and remote sensing of crop conditions, and characterizing spatial variability of crop conditions using multi-spectral imaging to develop treatment maps for use with aerial-applied, site-specific application systems.

When I worked as a Master student in Geo-science, I worked on drought monitoring over agricultural field using remote sensing, which mainly focused on the energy balance of the region. When I worked as a Ph.D. student in INRA of Avignon, France, I worked on angular effects of thermal radiation and the retrieving using airborne and an industry crane borne data. Currently, I work as a professor in Remote Sensing Institute, China Academy of Science in Beijing, China. I work on agricultural field environment monitoring and assessment using Satellite imaging, including the study on air and soil pollution monitoring of agricultural field.

We are glad to meet you and Dr. W. Clint Hoffmann when you visited our institute in July 2007. I think we had a good discussion for our potential collaborations for research projects in remote sensing. Thank you.

Sincerely,

Tao Yu, Professor
Institute of Remote Sensing
China Academy of Science
Tel: 86-10-64889562
Email: yutao@irsa.ac.cn

United States Department of Agriculture

Research, Education and Economics
Agricultural Research Service

February 12, 2008

Dr. Clint Hoffmann
Agricultural Engineer
USDA-ARS Areawide Pest Management Research Unit
2771 F&B Road
College Station, TX 77845

Dear Clint:

This letter is to confirm the intent of our research team to collaborate with the ARS scientists in the APMRU at College Station, Texas on a number of projects over the next five year period. We have been actively involved with your group for the past few years and look forward our continued working relationship. Specifically, we will contribute the following expertise:

- Providing analysis, training, and materials with respect to the detection and quantification of pesticide products, such as Imidacloprid, in plants and on artificial targets.
- Assessment of atomization characteristics resulting from varying operational settings on a number of ground application systems.
- Execution and analysis of deposition patterns spray product fate, and biological efficacy resulting from ground and aerial application of crop protection products into soybean and tree canopies.
- Development and testing of electronic sensors to detect volatile organic compounds associated with insect pest infestations and pesticide applications.

Sincerely,

Richard C. Derksen, Ph.D.
Agricultural Engineer

cc: Dr. Charles R. Krause, RL

ars

Midwest Area • Application Technology Research Unit
1680 Madison Avenue • Wooster, OH 44691
Voice: (330) 263-3863 • FAX: (330) 263-3853

Appendix 2: USDA 4.4 SOP

STANDARD OPERATING PROCEDURES

4. ATOMIZATION STUDY PROCEDURES EFFECTIVE DATE: September, 2007

USDA-4.4: DETERMINING CROSS-SECTION AVERAGE DROP-SIZE DISTRIBUTIONS OF SPRAYS

APPROVAL : _____ DATE:

APPROVAL : _____ DATE:

1.0 PURPOSE AND SCOPE

1.1 The purpose of this Standard Operating Procedure (SOP) is to establish standard methods for determining average drop sizes, specified by the volume median diameter ($D_{V0.5}$), and drop-size distributions for sprays of agricultural chemicals through commonly used agricultural spray atomizers. A wind tunnel is to be used in these calibration tests to simulate spraying from low-speed platforms such as tractors, medium-speed platforms such as helicopters, and high-speed platforms such as fixed wing aircraft. This method is to be followed for all wind tunnel studies conducted by/for the USDA-ARS in College Station, TX.

1.2 The purpose of this test method is to obtain data that characterize the sizes of drops of liquids used in agricultural sprays or liquid simulants of those materials that are produced under conditions similar to those encountered in actual applications. The sprays are to be produced in air streams moving at velocities from <2 miles per hour (mph) to 180 mph (<1 m/s to 72 m/s), to simulate sprays from tractors, ground sprayers, or aircraft. These drops will generally be in the size range from 2 μm to 3000 μm.

1.3 This test method is intended primarily to standardize measurements of sprays of agricultural formulations.

1.4 Although a common practice in making drop-size measurements with any laser-light particle sizing instruments is to make measurements along a single line-of-sight through the spray centerline, this Standard Operating Procedure defines a method requiring measurements across the entire spray cross-section or through several chords representative of the overall spray cross-section. This gives average spray characteristics representative of the entire spray rather than values preferentially weighted by the characteristics near the center of the spray obtained with a single, centerline measurement.

1.5 Use of this test method requires that the instrument be located outside the wind tunnel containing the spray so that the instrument shall not interfere with the process of producing the spray (by atomization of the liquid) or the air patterns in the region being examined--this technique is described as “non-intrusive.”

1.6 The computation of drop-size distributions from the light-scattering distributions is based on the assumption that all particles are spherical. Measurement of non-spherical particles may introduce errors.

1.7 The instruments shall include data processing capabilities to convert the laser-diffraction scattering intensities into drop size distribution parameters in accordance with E 799 and E 1296.

2.0 BACKGROUND

2.1 The drift of agricultural sprays of pesticides and other materials off the intended target and onto water supplies or other non-targeted areas can cause damage and risks that must be minimized. The chemicals may be sprayed from a tractor, a helicopter, or an airplane. The amount of drift may be estimated by computer models, where inputs to the model include the initial drop-size distribution, the vaporization rate of the material, the wind velocity, the air temperature, the topography, and other variables. These studies may be used to determine those conditions under which it is reasonably safe to spray chemicals with a minimum risk of the spray drifting onto non-target areas.

2.2 One of the critical inputs in these estimates of spray drift is the initial drop-size distribution. Large drops tend to fall quickly to the ground due to gravitational forces, while small drops tend to drift due to the higher ratio of air drag forces to gravitational forces.

2.3 *This **Standard Operating Procedure** may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements refer to Section 10.

3.0 SIGNIFICANCE AND USE

3.1 The purpose of this test method is to provide a standardized technique for determining the initial drop-size distributions, including secondary atomization by high-velocity air streams, for agricultural chemical formulations as atomized by certain standard types of agricultural atomizers.

3.2 The results obtained will be the total droplet size distribution. Classes of instruments other than laser-diffraction instruments might be expected to give different results on similar sprays due to differences in sample volumes, differences in sampling weighing factors resulting from particle velocities (spatial or flux weighted), differences in size range capabilities, and other factors. However, the sampling of the entire cross-section of the spray does remove the line-of-sight integral sampling volume usually associated with laser-diffraction particle sizing instruments, and provides a basis for comparison with measurements by other classes of instruments when those measurements are processed to determine cross-section average spray characteristics.

4.0 REAGENTS AND MATERIALS

4.1 In many cases the spray-producing devices to be tested will have been designed to operate with a single specific liquid. This may be of any kind, including flammable, toxic, or otherwise hazardous substances, although water is the most common. It may be desirable to use an alternate liquid to simulate as closely as possible the physical properties of the specified liquid such as viscosity, surface tension, and density. For these tests, the formulation to be tested shall be specified.

4.2 Whatever liquid is used for testing purposes, the liquid temperature shall be maintained at the specified temperature within a range of 18°-32°C (64°-90°F).

4.3 Physical properties of spray materials will be measured using USDA-4.2 "Measurement of Physical Properties of Liquids".

5.0 INSTRUMENTATION

5.1 The standardized drop-sizing instrumentation to be used for these tests is a laser-diffraction particle sizer. The preferred manufacturer is Sympatec, but there are also other acceptable suppliers. This procedure describes a method to obtain an average measurement across the whole spray cross-section so that spatial differences in the drop-size distribution are correctly weighted.

5.2 The measurements made with laser-diffraction instruments are number-density-weighted rather than number-flux-weighted as in some other types of instruments,

especially single-particle-counting instruments (*e.g.,* PMS OAP and Aerometrics phase-Doppler). Number-density-weighing is often referred to as spatial sampling, and number-flux-weighing is often referred to as a flux-sensitive sample, but these latter terms are ambiguous. The number-density-weighted instruments utilize a sample volume and weight the averages calculated by the number of drops within the sample volume. The number-flux-weighted instruments establish a plane within a sample volume and weight the averages calculated by the number of drops passing through the plane. The number-flux-weighted samples are not affected by changes in the relative velocities of the drops, while the number-density-weighted samples preferentially weight the slower moving drops. Thus, the number-flux-weighing instruments (*e.g.*, PMS OAP and Aerometrics phase-Doppler) have the advantage of providing drop-size samples invariant with sample distance from the atomizer if the complete cross-section of the spray is properly sampled and if evaporation, coalescence, and recirculation are insignificant. In contrast, number-density-weighing instruments provide drop-size samples that, in general, vary with sample distance from the atomizer as drop velocities relax to the air velocity at different rates depending on their size. Variations across the cross-section of the spray are typically larger than the velocity bias errors associated with number-density-weighted sampling.

a. For cases where the wind tunnel velocity is greater than the initial downstream axial component of the spray velocity, the number-density-weighing will preferentially weight the larger drops, and the measured average sizes will be larger than the "true" average sizes. For atomizers mounted at 90° to the air flow, the air velocity will always be greater than the downstream axial component of drop velocities. For coaxial mounting the following may be used to estimate the initial drop velocities. The initial axial velocity of the spray depends on atomizer design, but for a pressure atomizer, a pressure differential of 30 psid (207 kPa) should produce an axial drop velocity between 23 to 37 mph (33 to 53 ft/s, 10 to 16 m/s). For 60 psid (414 KPa), these initial spray velocities would increase by a factor of 1.41.

5.3 The laser-diffraction particle sizing instrument shall consist of a laser, optical means for producing a collimated beam that passes through a region of the spray, detectors for recording scattered light energy resulting from the liquid drops, and means for transforming the observations into statistical estimates of drop size and dispersion characteristics. The instrument shall have a bias of less than 3 percent as determined by measurement of the volume median diameter ($D_{V0.5}$) using the photomask reticle as described in Section 6.

5.4 Operating instructions for the laser-diffraction instrument shall be supplied by the manufacturer or contractor of the apparatus or instrument. The instructions should contain:

a. Brief description of the operational principles of the instrument, oriented towards a trained technical operator. Reference to relevant published literature shall be included in an appendix

b. Recommendations for installation and use of the apparatus

c. Range of ambient temperature, humidity and line voltage variation, and any known limitations on the operating environment

d. Ranges of liquid particle size and number density or some equivalent parameter for which the instrument is designed

e. Maintenance procedures recommended and required

f. Calibration or validation procedures

g. Statement of bias, repeatability, and reproducibility of the resultant drop size data

5.5 A wind tunnel suitable for atomization studies is necessary for these tests. The tunnel dimensions at the testing section are dependent upon the air velocity range, nozzle type and its orientation, and must be sized large enough to ensure a complete scan of the spray plume, typically over 18 inches (46 cm). For velocities below 20 m/s (45 mph), a minimum dimension of 60 cm *x* 60 cm is required. For velocities above 50 m/s (112 mph), a dimension of 40 cm *x* 40 cm is adequate. The air velocities required within the tunnel is dependent on the application methodology. For ground application scenarios, the tunnel should be capable of generating air velocities of 1 m/s (2 mph) to 10 m/sec (22 mph). For helicopter and fixed-wing aerial application scenarios, the air velocities should be 18-45 m/sec (40-100 mph) and 45-80 m/s (100-180 mph), respectively. All wind tunnels used in atomization testing should meet the following specifications:

a. Variations in velocity with time measured at the center of the tunnel shall not exceed 5 percent from the specified velocity. The velocity measurement may be made by Pitot tube, laser-Doppler anemometry, or other techniques whose accuracy and time response are sufficient to determine the velocity within the specifications given.

b. Spatial variations in velocity across the test section shall not exceed 10 percent of the specified velocity for the region from the centerline to 80 percent of the distance from the centerline to the walls of the test section.

c. The relative humidity shall be measured and reported.

d. The air temperature in the tunnel may be the ambient air temperature and shall be measured and recorded. Normally, a maximum of 40°C (104°F) should not be exceeded - unless specifically required for a test and the evaporation rate must be considered.

6.0 CALIBRATION AND STANDARDIZATION

6.1 Laser-diffraction instruments use a theoretical relationship (Lorentz-Mie theory) between scattered energy and particle size to obtain particle-size distributions from measured near-forward scattering patterns. Using detectors of known scattering angle, area, and relative responsivity, the calibration is defined from Lorentz-Mie scattering theory without resorting to external calibration sources. However, calibration standards are necessary to verify the correct operation of the instrument. Further information and background is provided by Dodge (1984), Hirleman and Dodge (1985), and the Sympatec Helos User Manual (2004).

6.2 When using laser diffraction equipment, the correct operation of the instrument shall be verified with a photomask reticle before beginning any set of tests or as frequently as required in the instrument standard operating procedure. The Sympatec Helos should be calibrated each year by a factory representative. This calibration can be checked periodically using a photomask reticle. The results of measurements with the reticle shall be included in the test results, along with the acceptable [expected] value(s) for the reticle. These may include values for X, N, D_{32} or $D_{V0.5}$. If more than one of the measured values differs from the acceptable value by more than 3.0%, the instrument shall be checked for misalignment, dirty optics, *etc.*, and the reticle remeasured after appropriate corrections have been made. The errors should be less than 3.0% before the instrument is used for testing.

6.3 The Sympatec Helos has an auto alignment feature that eliminates the beam wander commonly found in older laser diffraction instruments. Prior to each replication or spray test, a beam alignment and background measurement should be made by pressing F2. The background reading should be measured with the wind tunnel running at the required velocity before every test run. A significant or high reading on any of the channels is an indication of lens contamination; therefore, the lens should be cleaned using cloth and acetone. Before starting the actual measurement, an additional 5 second background reading should be made by pressing the F3 key.

6.4 If significant background shift from one run to the next is noted, then check the lens for contamination. If contamination is found to be the cause, then the last run must be repeated, and the run in question invalidated, as needed.

7.0 TEST METHOD

7.1 For a facility where the spray cloud is scanned through a stationary laser beam, mount the nozzle [atomizer] on a traversing mechanism (vertical) and position in the wind tunnel as required. For low air velocity tests, the nozzle should be oriented such that the spray cloud is parallel to the airflow. In general, the positioning and traversing procedures should be followed as described in the Testing Facility's SOPs and / or as in Sections 8 and 9.

7.2 The agricultural chemical "formulation" or simulant to be tested is maintained at near constant temperature (as indicated in section 4.2) to maintain constant physical properties, and is supplied to the atomizer at a constant pressure. The temperature should be recorded for each tests as specified in the testing protocol.

7.3 Measurements of the spray are conducted by passing a laser beam through the spray with individual drops in the spray scattering light at angles characteristic of their size. Both the scattered light and the unscattered light are focused by a collection lens such that all light scattered at a given angle is directed to a common circle centered about the unscattered light beam.
The scattered light energy is measured by a series of annular diode detectors centered about the unscattered light beam or other means of detection are sometimes used. The relative energy of the scattered light at several scattering angles is sufficient to infer the particle size distribution. The unscattered light energy is measured both with and without the spray present to determine the extinction (total fraction of light scattered by the spray), to calculate the liquid spray density, and to estimate the probability of a photon's being scattered from more than one drop before reaching the detectors, which would introduce errors into the measurement

7.4 Procedures are available under some circumstances to correct for errors due to photons scattered from more than one drop, as discussed in section 12. The relative energy of scattered light is processed based on Lorentz-Mie scattering theory to estimate the particle size distribution producing the scattered light energy. The particle-size distribution may be described by a multiple-parameter function such as those described in ASTM E1296 (**9**), or it may be described as the relative population of particles in discrete size classes. These distributions are further analyzed to determine mean sizes and dispersions.

7.5 This test method describes sampling procedures suitable for laser-diffraction instruments used to obtain a particle-size distribution representative of the entire cross-section of the spray at a given axial location from the spray source.

7.6 The spray atomizer shall be positioned relative to the sampling laser beam in accordance with the sampling requirements specified in Section 9.

7.7 The spray atomizer shall be operated in accordance with guidelines given in Section 8.

8.0 PROCEDURES

8.1 Install the nozzle in the wind tunnel at or near the centerline at the appropriate orientation to the airflow (generally 0 - 90°) with the nozzle tip at an upwind distance of 15 - 60 cm (6 - 24 in.), accurate to 1.25 cm (0.5 in.), from the center of the laser beam. This distance must be determined for each nozzle type to ensure sampling occurs after atomization in complete.
For tests with the nozzle orientations between 30° - 90° and low air velocities, it may be necessary to increase the upwind distance of the nozzle from the laser beam. This is to allow for the trajectory change necessary for the spray cloud to pass through the laser beam. Similar adjustments may be necessary for specific nozzles, such as straight jets, to allow adequate distance for complete atomization.

8.2 Because of the many possible test combinations, it is recommended that the particular test requirements be checked visually prior to any measurements being made. It is important that the nozzle or instrument can be traversed so that the upper and lower limits of the spray cloud can be passed through the laser beam.

8.3 Position the Sympatec Helos transmitter on one side of the tunnel and the receiver on the other. Preferably, they should be on a common mounting gantry that allows for some height adjustment of the laser beam within the tunnel. Ensure that the optical alignment is correctly adjusted. Ensure that the instrument is stable and that vibrations are minimal.

8.4 The R5 lens is to be used as the standard lens. This allows adequate working distance along the beam to avoid any problem due to vignetting. For a very fine spray cloud it may be necessary to use a shorter focal length lens but, in such cases, it is essential to check that the spray cloud is accommodated. For coarser sprays it may be necessary to use the R7 lens.

8.5 For a facility where the laser itself is moved and the laser beam is traversed across the spray cloud, it is essential that there is sufficient vertical movement to allow complete sampling of the cloud under all operating conditions.

8.6 The laser beam should be uninterrupted in its path across the tunnel by passing through suitably positioned holes or slots in the tunnel sides. The use of glass or plastic windows will increase problems of beam distortion and should be avoided. While in use, the external air should be drawn into the tunnel through any such

opening; this will minimize the escape of any spray droplets and any lens contamination. If the tunnel pressure is not negative, take other means to minimize contamination and leakage.

8.7 ALL personnel working at the USDA Facilities must read and sign the USDA Laser Safety Form prior to starting any tests. Specifically, all personnel must:

- Observe necessary safety precautions for the use of the laser and the supply voltage;
- Do not introduce reflective objects (*e.g.,* the nozzle) into the laser beam;
- Do not look directly into the laser beam;
- Observe safety precautions for the other electrical power requirements in the presence of sprayed liquids that may be electrical conductors.

8.8 Check the calibration of the Sympatec Helos in accordance with Section 6 and the instrument's SOP.

8.9 Use a temperature measuring device with an accuracy of ±0.1°C to measure the ambient air temperature and spray liquid temperature.

8.10 Monitor the delivery pressure as close to the atomizer as possible using a calibrated pressure indicator without disturbing the airflow profile. Maintain the delivery pressure within 2 percent or 2 psi (14 kPa) of the specified pressure, whichever is larger, throughout each spray replications. If the atomizer requires air assist, set the air-assist pressure to the specified pressure and maintain it within 10 percent of the specified pressure. Use a pressure measuring device(s) with an accuracy specification appropriate for this requirement.

8.11 Set up the liquid supply, wind tunnel parameters, instrumentation and facilities in compliance with the appropriate accompanying SOPs.

8.12 The sampling locations, axial and radial, shall be in accordance with Section 9.

8.13 Generally, commence testing with the R5 lens. If necessary, replace the receiver lens with the appropriate lens. Make adjustments to the optical system as described in the Sympatec Helos manual in order to center the drop size distribution best within the operating range of the system. Refer to the manual for specific guidance.

8.14 Spray or any contamination on optical surfaces of the instrument or windows confining the spray will seriously degrade instrument performance. Tests must be limited to those configurations and conditions for which there is no spray impact on the optical surfaces where the laser beam passes through the optics. Air flow is generally required to remove drops to prevent impact on optics.

8.15 Refractive index gradients in the air due to large temperature or concentration gradients can cause the laser beam to be deflected or diffused so that a false signal

is created near the centerline of the optical system. Vibration of the particle sizing instrument results in a similar erroneous signal. Under these conditions measurements with a laser-diffraction instrument are invalid, and the adverse conditions must be removed. Vibration of long focal length (800mm and greater) lens is of considerable concern. The vibrations typically induce significant noise in the first or second channel. Masking these channels is acceptable assuming that no droplet data is measured within two channels. This insures that the measurement is not biased.

8.16 Optical Concentration (obscuration) shall not exceed 60% during replicate measurements. Additionally, measurement start trigger should be set to initiate when optical concentration reaches 2%, and measurement should continue until optical concentration is sustained at less than 2%.

9.0 SAMPLING PROCEDURES

9.1 The axial distance from the atomizer to the measurement location is determined by the following criteria. Locations too close to the atomizer may give results biased by incomplete breakup of the spray, and are also subject to measurement bias due to non-equilibration between the air velocity and the drop velocity. Locations too far from the atomizer will increase the likelihood of spray impact on optical surfaces in the sample beam path. Additionally, the wind tunnel diameter at the site of measurement should be approximately three times the diameter of the spray plume.

a. For most tests, a nominal distance of 6-30 in. (15-76 cm), accurate to within 0.5 in. (13mm), shall be used between the center of the atomizer tip and the plane of the measurements. The plane is defined by the movement of the centerline of the laser beam as it traverses the spray. The experimental set-up must insure complete span of the spray cross-section, particularly when the atomizer orientation is perpendicular to air velocity.

b. If straight jet nozzles are being tested, greater than 30 inches (76 cm) may be required to ensure complete representative atomization, and since the atomization is not occurring until greater distances, evaporation is not a factor until distances after stream break-up.

9.2 For rotary atomizers, the atomizer must be attached to a support, such as a section of the aircraft boom, mounted horizontally through the center of the wind tunnel. The atomizer should be securely mounted to minimize movements and vibrations within the wind tunnel. The cage or screen should be oriented parallel and slightly downward to the airstream direction to ensure that the windmill blades (for blade-driven atomizers) are perpendicular to the airstream. The liquid supply hose must be securely clamped close to the mounting support to minimize obstruction of the airflow

a. The atomizer rotation rate under load (*i.e.*; while spraying) should be monitored using an inductive pickup or optical tachometer.

b. If the flow rate is monitored using a flowmeter, this must be calibrated for each test substance under study that may have different physical properties.

c. The rotary atomizer cage, screen, or zero issuing surfaces must be clean and free of particulates or blockages that may affect liquid atomization.

d. Care should be taken when positioning the atomizer to ensure that the spray does not contaminate the laser diffraction equipment, beam expander, or collimating lens. The atomizer must also be far enough from the laser beam to ensure that atomization is completed and that ligaments or sheets are not being sampled.

9.3 Nozzles being sampled are traversed vertically through the wind tunnel making sure that spray plume is not affected by tunnel edge. Traverse of spray nozzle typically requires 15-20 seconds, depending on spray plume geometry. Electronic controls insure that all spray traverses are made over approximately the same time scales. All nozzles mounted and tested on the traverse require the same time span for droplet size measurements.

10.0 PRECAUTIONS AND SAFETY

10.1 These tests may involve spraying materials that are toxic, flammable, and/or hazardous in other ways. The flammability or toxicity of the material may be greatly increased by the production of the material in the form of a spray where it may be burned or inhaled more readily. This procedure cannot address all possible hazards, and it shall be the responsibility of the operator to consider such hazards and take all necessary precautions. This includes the collection and disposal of hazardous waste created in the process of performing these tests.

10.2 These tests involve the use of a laser that can cause eye damage. Although the lasers used are typically low in power, the user of this procedure must take precautions to guard against eye damage from the laser.

12.0 LITERATURE CITATIONS

12.1 Annual Book of ASTM Standards, Vol. 14.02:

a. E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

b. E 456 Definition of Terms Relating to Statistical Methods

c. E 799 Practice for Determining Data Criteria and Processing for Liquid Drop Size Analysis

d. E 1296 Standard Terminology Relating to Liquid Particle Statistics

12.2 "Determining Cross-Section Average Drop-Size Distributions of Agricultural Sprays in a Wind Tunnel", Standard Operating Procedure, Southwest Research Institute, San Antonio, Texas.

12.3 "Standard Test Method for Determining Cross-Section Averaged Liquid Drop Size Characteristics in a Spray Using Laser-Diffraction Instruments.", ASTM Subcommittee E29.04, Draft Standard.

REFERENCES

Dodge, L.G., "Calibration of the Sympatec Helos Particle Sizer," Applied Optics, Vol 23, 1984, pp.2415-2419.

Hirleman, E.D., and Dodge, L.G., "Performance Comparison of Sympatec Helos Instruments Laser Diffraction Drop Size Analyzers," Proceedings ICLASS-85, 3rd International Conference on Liquid Atomisation and Spray Systems, Institute of Energy, London, Vol 2, 1985, pp. IVA/3/1-14.

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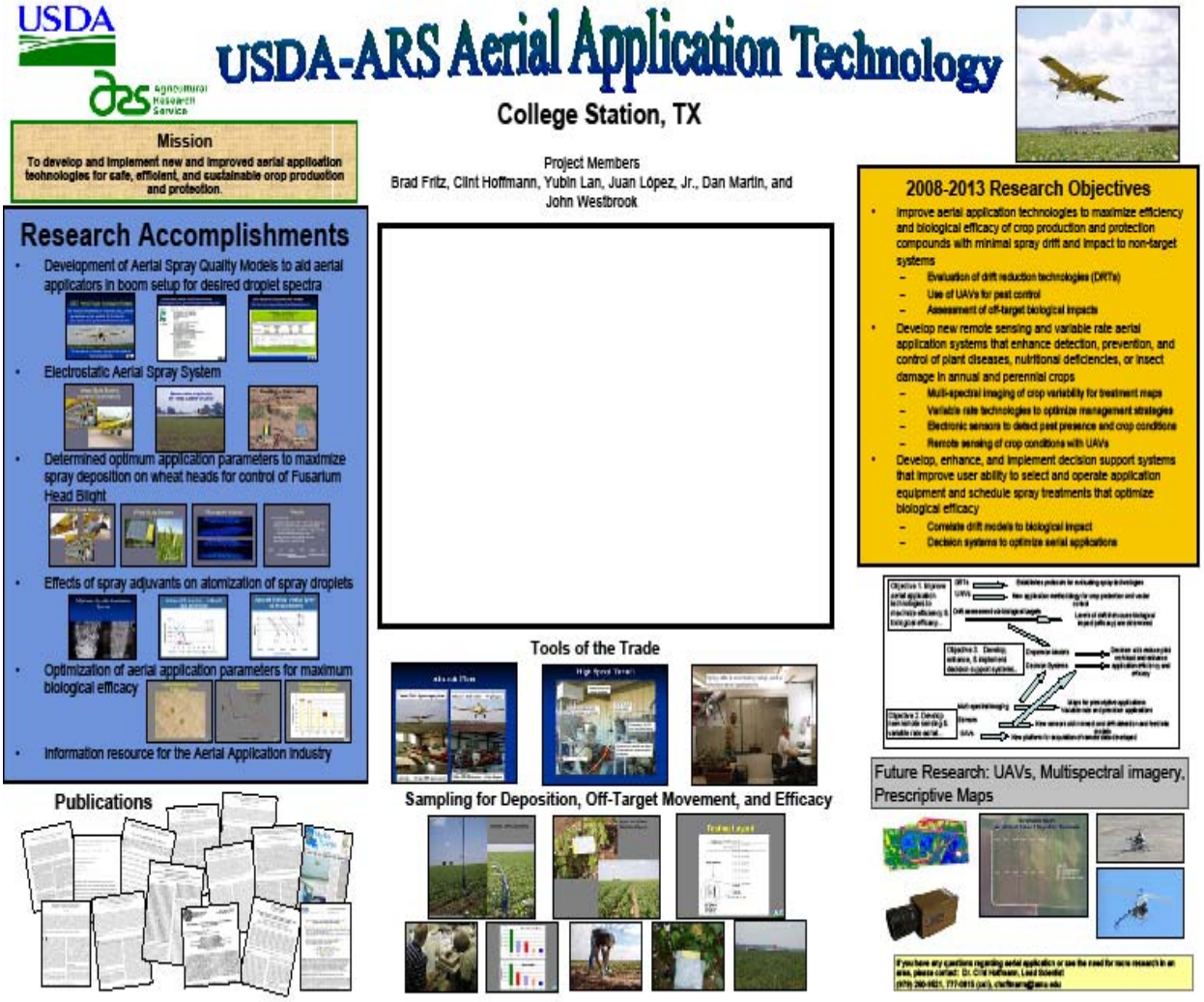
Appendix 3: Trade Show Poster