Nominating Region: South

Nominator: Randy Raper **E-mail:** Randy.Raper@okstate.edu

Project or Committee Number and Title: S1069 Research and Extension for Unmanned Aircraft Systems (UAS) Applications in U.S. Agriculture and Natural Resources

Technical Committee Chair: Lav Khot **E-mail:** Lav.Khot@wsu.edu

Administrative Advisor: Randy Raper **E-mail:** Randy.Raper@okstate.edu

PROJECT SUMMARY

Issue, problem or situation addressed. Unmanned aerial systems (UAS) use in agriculture and natural resources was in its infancy until this group was formed, and substantial development was needed to enable routine use in commercial production. This was a key reason this multistate research project was established. Biotic and abiotic stresses are key limiting factors in crop and animal production and in managed ecosystems, so characterizing plant and animal behavior in response to changing environmental conditions is a critical pursuit for researchers across the country. Such activity is necessary for breeding and genetic improvement and for maximizing resilience and productivity in managed agricultural systems. Remote sensing with UAS has the potential to characterize crops, animals, forests, estuaries and their various stresses at much higher resolution than previously possible. *However, the value of UAS in agricultural systems is predicated on continued research and Extension that clearly demonstrates reliable systems and viable workflows that provide optimum return on investment.* Agricultural systems are extremely complex, with many potential stressors that can appear simultaneously, and their measurable symptoms are often indistinguishable. Thus, scalable methods that have broad applicability across multiple fields, crops, times, and regions are essential to exploiting the benefits of UAS in production agriculture. While UAS data collection is becoming common in agronomic research, a perennial need remains for advances in the breadth, accuracy, and repeatability of measurements to enable positive economic impacts in U.S. agriculture. These impacts will require a wider knowledge base, consistent protocols, and metadata standardization. This multistate research group leverages its strengths to address such concerns.

Objectives. (1) Determine the optimal spatial, temporal and spectral resolution needed for actionable decisions from farmers (economic) and researchers (discovery) for the following specific applications: a) High-throughput field-based phenotyping; b) crop management; c) livestock management; d) forest management; (2) Test applications of UAS in specific real-world, production agriculture situations in multiple locations to determine: a) appropriate platforms and sensors; b) methods of calibration; c) detailed protocols for specific applications; d) appropriate data management strategies; e) benefits to researchers and producers; (3) Use UAS to detect stress and determine stressors in plants and related ecosystems to: a) develop a broader understanding of how UAS-based sensors can be used to detect biotic and abiotic stressors of plants and related ecosystems; b) develop models and calibration techniques that relate UAS-derived sensor data to the ground-truthed data; c) deliver the best measurement standards for detecting stress in plants and related ecosystems; and (4) Develop sustainable, decision-making information across geographic scales and locations.

Accomplishments. At the time S-1069 was conceived, the average university researcher had a series of challenges to acquire and utilize a UAS. Prior to substantive changes in FAA guidelines in 2016, research programs required individuals with a pilot's license, a visual observer who could pass a medical exam, and a government-issued certification of authorization permitting flight in specified areas. While producers expressed high interest in the technology, regulations were also strict regarding use of UAS for education, Extension, and private use. Against this backdrop, a multistate research project was created to leverage strengths that could advance this field. Since then, the members of S-1069 have met the project objectives with the following wide-reaching ***outputs***:

- Over 100 peer-reviewed publications, including 4 book chapters, on UAS to share knowledge and progress. The breadth of publication was wide, including 45 journals targeting a variety of disciplines and audiences. Almost 20% of the articles appeared in Remote Sensing (IF > 4.0), and Frontiers in Plant Science (IF > 5.7), international open access journals.
- Participation in academic conferences and regional Extension meetings. S-1069 members have been particularly active with presentations at the SPIE (International Society for Optics and Photonics) hosted series on unmanned systems for agricultural optimization and phenotyping, as well as technical sessions during the international meetings of the American Society of Agricultural and Biological Engineers and the tri-societies (ASA, CSA, SSSA).
- Production of Extension materials and even multi-university led workshops on UAS, with at least one workshop held outside the U.S., demonstrating the wide reach of this project.
- Over $35M in competitive grant funding for research and Extension with UAS, including multi-university awards, with at least three proposals resulting directly from this project.
- Matriculation and graduation of graduate students with advanced knowledge of UAS, some of whom transitioned to Ph.D. positions and faculty positions at other affiliated universities as a direct result of collaboration between S-1069 members.

S-1069 progress in UAS for high throughput phenotyping (HTP) serves as an illustration of how S-1069 has generated ***outcomes***. S-1069 members published lessons learned on incentivizing collaboration and on the social constraints and metrics of organization that can serve as barriers. Furthermore, awareness regarding genotypes and phenotypes has also been increased, resulting in a *change in behavior* as breeding research programs around the country increasingly use UAS for HTP. A *change of condition* is evidenced by the (now common) knowledge that UAS can be used to measure plant height, an activity that previously involved laborious effort. The end result is that S-1069 has enabled an order-of-magnitude increase in the number of genotypes considered by breeders, leading to more accurate selections, and rapid advances in crop improvement. The resultant ***benefit*** to external stakeholders is that improved cultivars are among the most economic and environmentally scalable. The ***direct impact*** of this project is that we now have tools to evaluate the responses of various genotypes to associated stresses, which is of critical importance as the climate changes and as pests adapt to current control methods. Other areas of collaborative research that offer similar potential for economic and environmental benefits include: (1) discovering how pests and disease can be detected by UAS before economic yield loss thresholds are reached (Integrated Pest Management); (2) integrating weather with crop data to develop predictive models for data-based production management decisions and resource maximization (e.g., water use); and (3) targeting production practices that contribute to surface water issues through responsible application of chemicals and remediation of off-target effects. The first five years of S-1069 laid the foundation for research these areas, and the research in the next five years of the multistate project will build upon this foundation.

As a specific example of the ***social benefit*** accrued by S-1069, a group of members at one university was uniquely positioned to provide UAS-collected 3D models based on their archival data of native American historical sites to tribal members following destruction of the site by an EF2 tornado. The 3D model serves as the basis for reconstructing the damaged property. Survivors were provided smaller 3D-printed models as a means to connect those afflicted by the event. Additionally, members have applied their skills and knowledge to global issues, as evidenced by provision of UAS training in programs such as Engineers without Borders.

Added-value and synergistic activities across mission areas. S-1069 is a diverse group with varied specializations. This fact has resulted in ***multi-disciplinary activities*** such as developing hardware-software systems and protocols that maximize data accuracy for capturing plant canopy reflectance, plant height, and plant canopy temperature as a result of collaboration among engineers, crop breeders, and remote sensing scientists. Multi-institutional synergy is demonstrated in the sharing of a design between S-1069 universities, in which a 3D-printable custom UAS-payload mount (which could be printed for $12 versus $400 for a market option) enabled agronomists at one university to enhance data collection capacity in four funded projects. We have also demonstrated ***multi-function integration*** with the UAS User Log, a digital log book for UAS operations in both research and production agriculture. The combined multi-discipline experience of members with differing research thrusts was critical to making this a flexible, comprehensive tool. S-1069 has been instrumental in assembling the human capital and expertise for UAS at land grant and other universities. Knowledge of expertise available within each university and targeted graduate student training in specific areas created a university network capable of responding to a wide range of issues. This connectivity has been shown to be particularly advantageous for universities looking to fill faculty vacancies for specific skills, and also to complete graduate committees requiring specialized expertise.

Evidence of multi-institutional and leveraged funding with examples of sources.

- *Enhancing accessibility, reliability, and validation of actionable information from unmanned aerial vehicle image data* (USDA NIFA award 2018-67021-27668), Mississippi State University (lead), partnering with Texas A&M University, University of Illinois
- *High intensity phenotyping sites: Transitioning to a nationwide plant phenotyping network* (USDA NIFA award 2020-68013-32371), Mississippi State University, Texas A&M University, plus other non-S-1069 affiliates
- *RFID and Beyond: Using RFID, Drones, and BLE to improve plant inventory management* (Horticultural Research Institute), University of Arkansas, partnering with Clemson University

S-1069 efforts also promoted standardization in protocols, which is critical to further collaborative work between universities. These efforts have resulted in meaningful technology transition to stakeholders, as well as development of a broader scientific knowledge base in several disciplines (e.g., applied agriculture, ecology, and environmental science).

Participating institutions and units

Auburn University

Arkansas Cooperative Extension

Cornell University

Clemson University

Louisiana State University

Mississippi State University

Montana State University

North Carolina State University

North Carolina Cooperative Extension

North Dakota Cooperative Extension

Ohio State University

Purdue University

Rutgers University

Stephen F. Austin State University

Texas A&M AgriLife Research

Texas A&M University

University of Arkansas

University of Florida

University of Georgia

University of Illinois

University of Kentucky

University of Tennessee

Virginia Polytechnic Institute and State University

Washington State University