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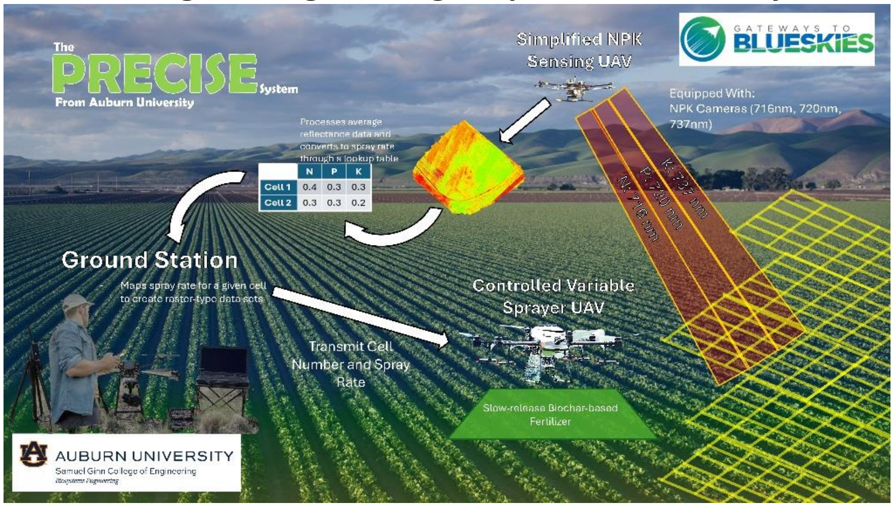
Samuel Ginn College of Engineering, Department of Biosystems Engineering

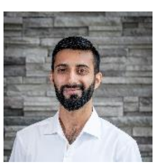


Proactive Resource Efficiency via Coordinated Imaging and Sprayer Execution (PRECISE System)

Technical Paper

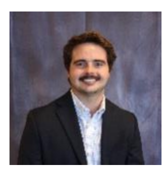
Team Members:

Team Lead: Vivian Usha
Graduate Student
Biosystems Engineering
Biochar/Biofertilizer Research

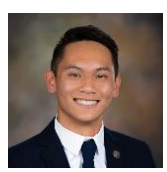


Hamid Syed
Graduate Student
Biosystems Engineering
Precision Agricultural Research

Ayden Kemp
Graduate Student/Senior
Bioprocess/Aerospace Engineering
Aviation Fuel, Computational Research



Louie Harris
Graduate Student
Biosystems Engineering
Precision Agricultural Research



Al Dean Francisco
Junior
Bioprocess Engineering
Wastewater Treatment Research

Faculty Advisor:
Tanzeel Rehman (Assistant Professor, Biosystems Engineering, Auburn University)
Jeremy M. Pickens (Assistant Extension Professor, Horticulture, Auburn University)

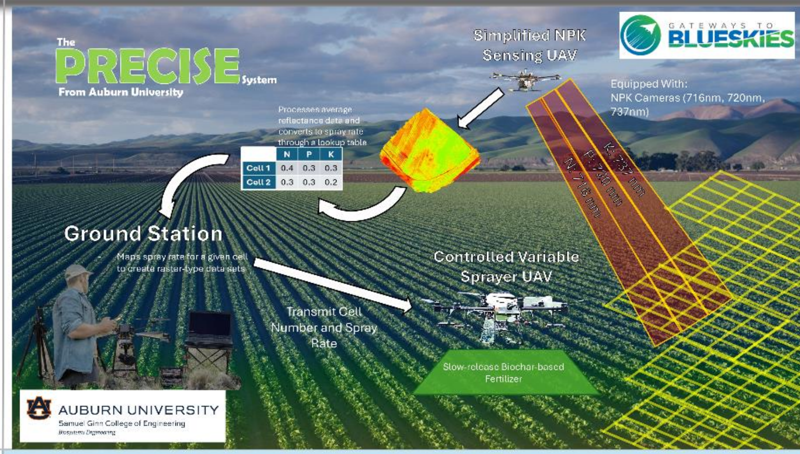
AUBURN UNIVERSITY
Samuel Ginn College of Engineering
Biosystems Engineering

Proactive Resource Efficiency via Coordinated Imaging and Sprayer Execution (PRECISE) *System*

GATEWAYS TO BLUESKIES

Project Summary:

The *Proactive Resource Efficiency via Coordinated Imaging and Sprayer Execution* (PRECISE) system innovates UAV-based remote sensing and fertilizer application technology to improve agricultural best management practices and maximize crop yields while minimizing eutrophication. New data acquisition and processing technology will decrease the time required to convert multispectral imagery into directions for sprayer application UAVs from hours to seconds without a loss in variable rate application (VRA) precision. Nutrient leaching will be further minimized by using locally sourced biochar-based fertilizer pellets within the sprayer UAVs for slow-release nutrient support for crops. Compared to traditional land-based application methods, PRECISE technology can save up to $84 per acre fertilized in combined economic and environmental impact.



The PRECISE Team

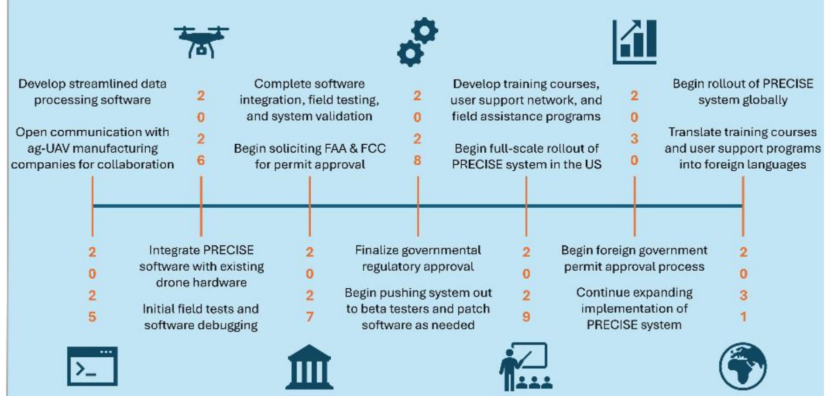
Department of Biosystems Engineering at Auburn University

- **Vivian Usha** Team Lead, Biochar Implementation
- **Hamid Syed** Precision Agriculture
- **Louie Harris** UAV Development
- **Ayden Kemp** Aviation Computational Design
- **Al Dean Francisco** Biochar Implementation

Statement

The Precise Team comprises of Biosystems Engineering students from Auburn University with different backgrounds and skillsets. Possessing a collective goal of and emphasis on sustainability for any designed system, the team has ideated a new technology to integrate existing hardware with new data collection and processing software to innovate UAV-based agriculture.

Proposed deployment timeline:



AUBURN UNIVERSITY
Samuel Ginn College of Engineering
Biosystems Engineering

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Abstract

Traditional land-based fertilization methods typically use an application rate determined by a farmer's personal experience, recommendations from local, state, or federal agencies, or time-consuming inspection of targeted areas throughout the field. These methods tend to result in low nutrient use efficiency as fertilizer may be over- or under-applied. Inefficiencies, such as these, can result in lodging, increased pest pressure, decreased yields, or nutrient runoff (Saleem et al., 2014). In recent years, unmanned aerial vehicle (UAV) based agricultural tools have employed multispectral imagery to accurately assess nutrient levels in a field and allow for variable rate application (VRA). However, these state-of-the-art UAV systems are only used sparingly because processing multispectral imagery data is computationally expensive and requires off-the-field cloud-based data post-processing to extract the information needed for downstream agricultural applications such as VRA. This poses a significant time constraint, which limits the ability of agricultural users to make real-time decisions and apply critical nutrients precisely when desired based on crop needs and weather conditions. Near real-time multispectral imagery processing and VRA would save time, labor costs, and allow for increased agricultural productivity due to better management of nutrients.

The proposed PRECISE (Proactive Resource Efficiency via Coordinated Imaging and Sprayer Execution) system is an autonomous UAV-based solution for ensuring the optimal application of nutrients to agricultural fields to allow for adequate fertilization and minimize nutrient runoff. Unlike existing systems, PRECISE employs streamlined multispectral imaging and near-real-time data processing technology. This eliminates the need for cloud computing and allows remote sensing and application of a slow-release biochar fertilizer to coincide with only a slight delay for in-field processing. Using PRECISE technology, fields are partitioned into a grid of uniformly user-designated size management zones. These zones are identified by the GPS coordinates of the zone center and a unique identifying number. The system then directs the flight of two quadcopter UAVs, a multispectral imagery UAV, and a fertilizer application UAV. The small multispectral imagery UAV flies over each zone and measures the average spectral reflectance in three specific wavelengths corresponding to nitrogen, potassium, and phosphorus (NPK) levels. A small onboard computer maps these values in a matter of seconds to a fertilizer application rate using a C++ lookup table. The imagery UAV then transmits the cell number and the target application rate back to the ground station, which stores the data as a raster map and directs the fertilizer application UAV to provide the given quantity of biochar fertilizer to the specific cells. The PRECISE system is a disruptive technology, integrating existing hardware with new data collection and processing software to revolutionize UAV-based agriculture that will save users both time and money. PRECISE technology can be quickly developed and deployed as a globally adaptable means to assist farmers in applying best management practices for maximizing yields and minimizing environmental impact, hence fostering sustainable agricultural practices.

1.0. Situational Assessment

Fertilizer has been used to increase agricultural yields since the Neolithic Revolution, nearly 12,000 years ago (Russel & Williams, 1977). As the world's population has increased, so has the intensity of fertilizer application. Traditional land-based fertilizer applications use trucks and tractors to distribute predominantly inorganic fertilizers over fields using a fixed application rate, often leading to nutrient runoff and eutrophication due to overfertilization. The United States Geological Survey (USGS) reported (USGS, 1996) that fertilizer and manure from agricultural production are the leading sources of nutrient pollution in rivers across the United States *(Figure 1)*. High leaching rates associated with chemical fertilizers and manure drive nutrient runoff into waterways, resulting in eutrophication (Smolders et al., 2010).

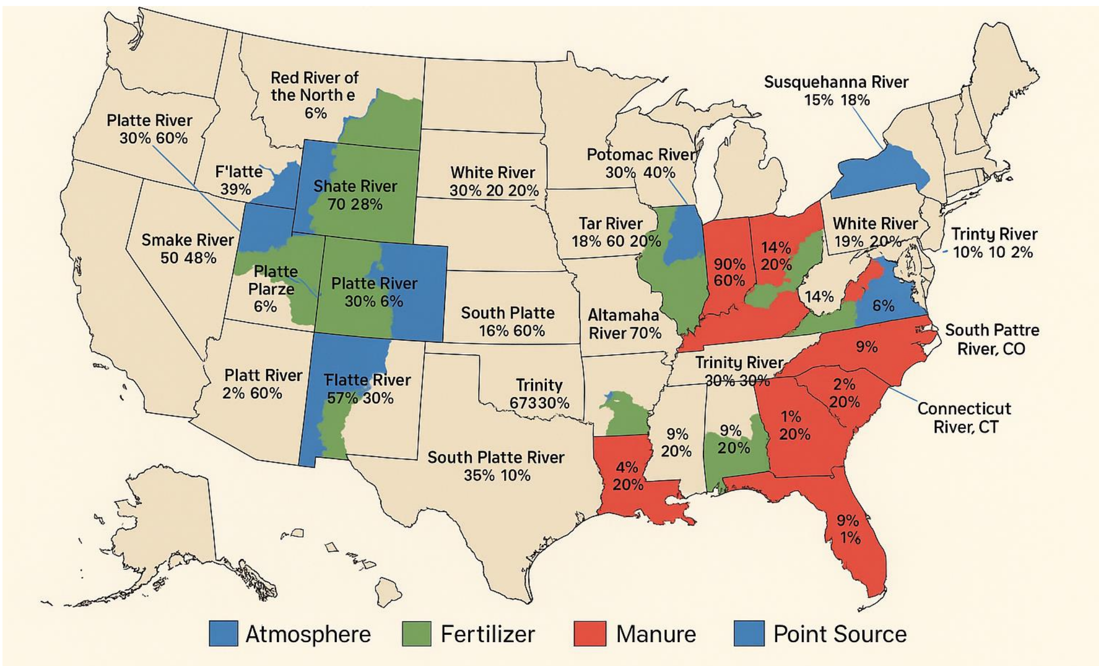

Figure 1: Nutrient load source in streams(USGS, 1996)

Nutrient pollution, exacerbated by climate change and increased precipitation in recent years, has led to the eutrophication of around 40% of US water bodies (Fernandez-Figueroa et al., 2024). Eutrophication results in diminished recreational water usage, reduced property values, and an increased need for water treatment, which in total costs the US approximately $2.2 billion annually (Dodds et al., 2009). It also leads to ecological degradation, loss of biodiversity, and other indirect impacts on local economies. With advances in science and technology, unmanned aerial vehicles (UAVs) may provide a solution to mitigate eutrophication by implementing targeted applications of fertilizers.

In recent years, UAVs have begun to be used more prevalently for agricultural practices, including assessing crop conditions using remote sensing and targeted fertilizer applications through variable-rate applications (VRA). Multispectral imagery capabilities allow the user to acquire an accurate overview of the health of an entire field before disease or nutritional deficiencies become apparent to even the most skillful farmers. Farmers can leverage processed imagery to guide spreader UAVs to precision-target specific field areas using VRA technology, applying the exact amount of fertilizer needed to meet crop requirements. This limits overfertilization and eutrophication while simultaneously saving growers money on fertilizer costs.

Despite these apparent benefits, only 5 and 25 percent of the total US planted acreage of most row crops utilize yield maps, soil maps, and variable rate technologies, with even less of a percentage utilizing UAVs (McFadden et al., 2023). Low adoption rates could result from the complicated processes involved in using current state-of-the-art (SOA) agricultural UAV technology. Current technology involves users uploading gigabytes of multispectral imagery data to online servers for cloud processing and downloading refined maps to instruct spreader UAVs on where to distribute fertilizer as shown in *Figure 2*. The time required for processing discourages many potential users from pursuing UAV-based VRA methods because fertilizer often needs to be applied during specific time frames based on crop needs and local weather. To keep up with the increasing demand for agricultural products while managing financial and environmental concerns, farmers need UAV-based VRA systems that simplify the process of responsible fertilization and do not complicate it further. Such systems could revolutionize agriculture in the US and throughout the entire world.

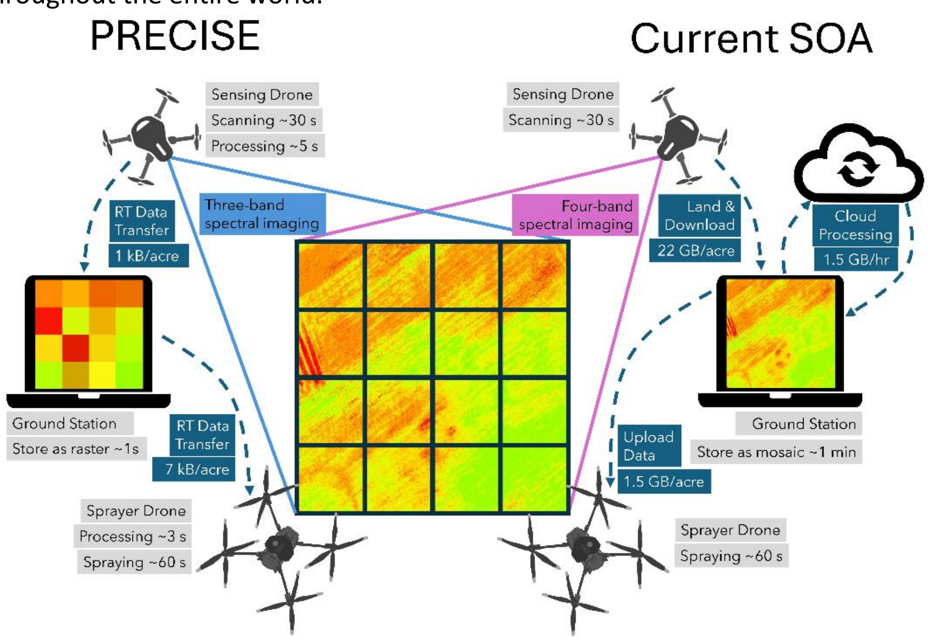

Figure 2: Comparison between the PRECISE-drone system and state-of-the-art drone systems

1.1. Use Case & Proposed Solution

The PRECISE system is a UAV system designed to assess field nutrient conditions and distribute fertilizer through VRA to minimize over-fertilization and under-fertilization of agricultural fields. PRECISE makes use of existing UAV and multispectral imagery hardware capabilities with new operating procedures and software to streamline data acquisition and shorten processing times compared to current agricultural UAV systems. This allows for the simultaneous operation of both sensing and spraying UAVs with only a momentary delay. Additionally, while being adaptable for distributing other agricultural fertilizers, herbicides, and pesticides, PRECISE is designed to distribute slow-release biochar-based fertilizers through VRA to maximize agricultural productivity while minimizing nutrient runoff, eutrophication, and environmental impact. This technology will be able to be rapidly developed and integrated with existing agricultural UAV systems globally to provide targeted VRA for important field crops such as corn and wheat.

PRECISE technology operates in two distinct phases: a pre-flight phase and an in-flight phase. In the pre-flight phase, the user delineates the boundaries of the target field or fields using a graphical user interface (GUI) with readily available GPS-tagged satellite imagery. The user draws a polygon around the target field by clicking on each vertex before double-clicking at the initial starting point to form a closed area. Next, the user defines the desired size of rectangular management zones, ranging from 25 m^2 to 50 m^2. At this time, the user alters other input variables related to fertilizer application rates based on the results of the remote sensing process, and can also mark any no-flight zones. Default settings will be programmed for users utilizing slow-release biochar-based fertilizer based on best management practices. The system then automatically generates a uniform grid based on the user-defined target area and sizing parameters. The system will account for edge effects for oddly shaped target regions and either exclude thin margins at a field's edge or include small portions beyond the borders of a field to ensure a rectilinear grid. The system then assigns each cell in the grid a unique identifying number. Finally, the GPS coordinates of each cell are preloaded to both a small quadcopter multispectral imaging UAV and a larger quadcopter spraying UAV.

The imaging UAV is equipped with a single three-band camera, a subset of the four bands typically used for multispectral imaging. These bands are for only nitrogen-phosphorus-potassium (NPK) analysis: a 716±20nm camera for nitrogen, a 737±20nm camera for phosphorus, and a 720±20nm camera for potassium (Balamurugan et al., 2024). Reducing the number of imaging bands reduces the processing power required for image processing. The UAV flies over each management zone and measures the area-averaged spectral reflectance at each wavelength for the cell. Using a small onboard computer, such as an NVIDIA Jetson, the average spectral reflectance values are mapped to a fertilizer application rate using a lookup table written in C++. This entire process will take a few seconds, and then the remote sensing UAV will transmit the cell number and target application rate back to the ground station before moving on to the next cell to continue NPK analysis *(Figure 2)*.

The PRECISE system's central ground station will store each cell's fertilizer application rate as raster data overlaid on top of the initial satellite imagery, connecting a given geographical area with its system-determined variable fertilization rate. The ground station then forwards the cell number and application rate to the spraying UAV *(Figure 2).* The spraying UAV then applies biochar fertilizer over each cell at a variable rate as determined by the imaging UAV. The entire process continues until both the imaging and spraying UAVs have completed NPK analysis and VRA for the entire target area. From the beginning of NPK analysis in a given management zone to the completion of VRA spraying, PRECISE requires less than 2 minutes. As needed during the treatment of large fields, the UAVs can return to a user-designated landing zone for rotating batteries and refilling the spreader UAV's hopper.

A slow-release biochar-based fertilizer is intended for use with this technology to help reduce nutrient leaching. Biochar is a black carbon residue from the pyrolysis of plant or animal waste. The production process of the fertilizer leverages the good adsorption properties of biochar to dope micronutrients such as magnesium and macronutrients such as nitrogen and phosphorus. Using chitin as a binding material, the doped biochar can be pelletized to form an easy-to-spread fertilizer. The presence of magnesium in the blend helps to create electrostatic attractions between biochar's atomic structure and that of the macronutrients, helping to store plant nutrients within the biochar pores, resulting in a slow release of nutrients and subsequently reducing nutrient leaching (Wang et al., 2022). Thus, having biochar-based fertilizer in unison with the PRECISE system provides excellent nutrient use efficiency for crops and allows for a natural way to increase yield, reduce fertilizer cost, and decrease pollution.

1.2. Operational Context

The PRECISE system can be implemented either as hardware upgrades and software updates for an existing UAV system (including the ground station) or as a ground station accompanied by hardware and software updates for the sensing and spraying UAVs. The technology will be designed to be compatible with most existing agricultural UAVs. This will enable existing system owners to implement PRECISE as cheaply as possible without replacing the most expensive hardware components. Additionally, as the system only requires electricity and satellite imagery from any one of several public-domain sources, this technology can be implemented worldwide to support agriculture in both developed and developing countries. Furthermore, as this technology will increase the appeal of UAV-based agriculture systems, increased demand for UAVs and multispectral imaging hardware will encourage market expansion, driving lower prices and enabling greater widespread implementation.

2.0. Implementation analysis

This improved system will allow farmers and companies to complete the data acquisition and treatment phases for a single field in a few hours, compared to a few days using the presently available systems. This system will be applicable throughout the United States and worldwide as users will only need access to a power source (a mobile generator is sufficient) and a supply of biochar-based fertilizer, which can be produced locally in most agricultural regions.

2.1. Integration Approach

The PRECISE system is a disruptive innovation that uses existing technology in a new manner to make the present process exponentially more efficient and accessible. Multispectral remote sensing capabilities are well-established, and the required cameras are at a TRL-9. As more sensitive cameras with better resolution become available, the system can quickly adapt to this improved hardware. The hardware for spreader UAVs is also at a high TRL-8 or TRL-9, with American-produced Hylio UAVs as one such example. Similarly, as UAVs with greater capacity and better battery life become available, the system can be adapted to those vehicles.

The hardware changes required for implementing the PRECISE system include upgrading antennas for transmitting data (in the case of the sensor UAV) and receiving data (in the case of the spreader UAV). The sensor UAV will also need processing or computing abilities beyond what is currently standard for these UAVs to convert multispectral data into application rates in real time. These capabilities are at TRL-6 and must be updated for specific use on the UAV systems. Regarding software, a new program for converting multispectral input into application rate will be written for use by the spreader UAV. While currently at TRL-2 or TRL-3, this required software can be quickly accelerated to a TRL-8 or TRL-9 by following the proposed detailed solution found in *2.5. Support System Requirements.*

During development, the PRECISE system will integrate both remote sensing and soil nutrient data. The small UAV collects multispectral imagery for canopy nutrient mapping (N, P, K), while soil sensors or targeted soil sampling assess nutrient levels at the root zone. Combining this data with predictive modeling can optimize fertilizer application based on canopy nutrient status and soil availability, ensuring precise nutrient delivery. This approach bridges the gap between canopy-level assessments and root zone requirements, improving fertilizer efficiency and crop growth.

2.2. Simplicity

The main draw of the PRECISE system is the ability to streamline the remote sensing, data acquisition, and data processing steps of current agricultural UAV systems so that sensing and spraying can coincide using the same ground station. Additionally, the user will only have to make direct inputs when initially discretizing the field into the desired cell-based grid, after which only limited supervision of the integrated system will be required. In return, the user will have significantly reduced labor in utilizing the data processing programs. Agricultural users will be drawn to this simpler system.

2.3. Relevance to Current Operations

The use of UAVs in agriculture has risen in the past 8 years due to new technology and improved application efficiency (Bayraktar et al., 2020). The main drivers of this change are improved UAV technology and lower operational costs when using UAVs for fertilizing compared to traditional ground-based application methods. However, most farmers/companies do not have the time to process large amounts of data in the field and have to go back to the office to process the data, often returning to the field a day or two later. With the PRECISE system, this major drawback is negated, and the use of UAVs, accompanied by reduced cost and environmental impact, will be accelerated.

The use of biochar in this application will mostly target phosphorus and potassium deficiencies in the field, as biochar is low in nitrogen. The PRECISE system is not specific to biochar-based fertilizer, offering the use of traditional fertilizer in the spreader UAV to help achieve high application rates of nitrogen while limiting the amount of leaching due to precise amounts of fertilizer being spread per quadrant to minimize waste and environmental impact.

2.4. Cost and Return on Investment

The PRECISE system will be compatible with existing agricultural UAV hardware to limit the cost of initial capital purchases for users. A preliminary techno-economic analysis (TEA) indicates that PRECISE, combined with separately obtained UAV and multispectral imaging hardware, could save users up to $2.22 per acre of crops fertilized every year for an annual total savings of $1,030 for the average American farm size (Schnitkey et al., 2020; USDA, 2024). Assuming initial capital costs for purchasing a multispectral imaging drone, a spreader drone, and the PRECISE system of $100,000, the time for return on investment (ROI) would be approximately 97 years. However, when the economic significance of the decreased environmental impact is considered, the savings increase to a maximum of $83.78 per acre fertilized for an annual total savings of $38,874. With this level of savings, the ROI would be 2.57 years. Additional savings will occur for growers with more than the average farm size of 464 acres or for growers in regions where fuel costs or fertilizer costs are particularly expensive. A detailed per-acre cost comparison among conventional chemical fertilizers administered by land-based methods, chemical fertilizers utilizing PRECISE technology, and biochar-based fertilizers likewise applied via the PRECISE system is shown in *Table 1*.

The analysis integrates financial costs with the comprehensive economic impact derived from life cycle assessment (LCA) metrics, encompassing eutrophication, greenhouse gas (GHG) emissions, acidification, and fossil fuel depletion. While traditional fertilizers and application techniques may appear more economical initially, they incur substantial subsequent environmental and financial burdens. The cost estimation demonstrates that biochar-based fertilizers combined with precision application provide an effective balance of economic viability and environmental sustainability. The increasing interest in carbon markets and sustainable agriculture suggests that PRECISE systems could deliver long-term value both economically and ecologically.

Table 1: Cost comparison of different fertilizer types and application techniques

Per Acre Cost Comparison ($)			
	Chemical fertilizer (Land-based application)	**Chemical fertilizer (PRECISE application)**	**Biochar-based fertilizer (PRECISE application)**
Techno-economic analysis			
Fertilizer production cost	$ 73.40	$ 73.40	$ 75.00
Application cost	$ 11.00	$ 20.00	$ 20.00
Capital cost	$ 8.17	$ 7.45	$ 7.45
Maintenance cost	$ 12.50	$ 2.00	$ 2.00
Total financial cost	**$ 105.07**	**$ 102.85**	**$ 104.45**
Life cycle assessment (Economic Impact)			
Eutrophication potential	$ 30.00	$ 25.00	$ 12.00
GHG emissions	$ 12.39	$ 12.23	$ 3.72
Acidification potential	$ 52.00	$ 39.00	$ 24.70
Fossil fuel depletion	$ 40.04	$ 38.80	$ 10.85
Total Cost	**$ 239.50**	**$ 217.88**	**$ 155.72**
Difference in using PRECISE		**$ 21.62**	**$ 83.78**
Assumptions *Row crops, for 1 acre coverage *Application rate = 0.1 – 0.25 tons *Application costs = $7 - $15 (Land-based) and $15 - $25 (PRECISE) *GHG reduction = 50% -90% when using biochar-based fertilizer alongside the PRECISE system (Possibility of carbon credit)			

2.5. Support System Requirements

For the PRECISE system to operate successfully, users must have access to biochar-based fertilizer, power for recharging UAVs, and initial satellite imagery. The biochar fertilizer can be produced locally by individual users or at a central facility (a community co-op) using agricultural or forest residuals. Current state-of-the-art spreader UAVs have a battery capacity of 8-10 minutes, while a battery takes 8-12 minutes to charge rapidly. System users could cycle through 2 or 3 batteries, with the drained batteries recharged using a portable generator. Satellite imagery is easily accessible through various open-source means. Only low-resolution images would be needed for users to delineate field boundaries and for the software to auto-generate a uniform grid.

Following grid generation on the ground station, the grid coordinates will be transferred to both the small imagery UAV remote controller and the large spreader UAV remote controller via an Ethernet connection or through a robust communication link, such as Wi-Fi. The frequency of this communication can typically range between 2.4 GHz and 5.8 GHz, depending on the specific drone communication protocols in use and the environmental conditions.

The fertilizer spray rate data generated by the small imagery UAV, equipped with an onboard computational unit, is transmitted to the remote controller's software platform using Real-Time Messaging Protocol (RTMP). This data includes real-time video feeds and other imaging information necessary for drone flight and control. The spray rate data, along with the UAV's status and position, is then passed from the remote controller to the ground station.

Once the spray rate data reaches the ground station, the more powerful computing capabilities available there are used to convert the spray rates into a raster dataset overlaid on top of the original satellite imagery used for generating the rectilinear grid in the pre-flight phase. The ground station will also forward the spray rate data to the remote controller of the larger spreader UAV.

From the remote controller of the larger UAV, instructions based on the spray rate data are sent back to the larger drone, ensuring accurate execution of tasks, such as targeted applications. The communication between the remote controller and the larger UAV also utilizes RTMP for efficient data streaming, ensuring minimal delay and reliable performance throughout the operation. This seamless flow of data between the small and large UAVs, coordinated via RTMP and Wi-Fi, ensures optimal utility and operational efficiency for the entire system.

2.6. Connectivity and Hardware Constraints

Current UAV systems require both GPS and internet access. GPS is used to locate and tag images and data. At the same time, an internet connection is required to upload data to DJI servers for processing and then to download the processed final data back to the user's system. The PRECISE system will still require access to GPS. However, it will eliminate the need for internet access for data processing (occasional internet access for software patches and updates may be required). This is especially important as broadband internet access can be limited in rural areas. This is one of the main draws of the proposed system because users will not need internet access. In rural agricultural areas with limited internet access, users will not have to travel to a location with a stable internet connection. They can continue working onsite, completing the sensing and spraying operations in one trip to a given area.

The hopper size on UAVs constrains the amount of fertilizer they can apply per hour. With a hopper size of 110 pounds, an average application rate of 100 pounds per acre, and a 10-hour workday limit, a single drone can cover 66 acres per working day. This calculation assumes 1.1 acres per flight and six flights per hour. However, if the UAV only needs to cover 70 percent of the field, its total covered acres will increase to 95 acres per day. Additionally, this calculation assumes a steady rate of 100 pounds per acre, but the actual amount of nutrients needed may vary depending on the field's nutrient content, which could affect the flight times required. Another factor is adding another spreader UAV to double the coverage and speed up the amount covered. The smaller size of the imagery and processing UAV allows it to cover a larger area daily, surpassing the spreader UAV's capabilities without causing a bottleneck.

2.7. Environmental Limitations

The limitations of the system posed by environmental conditions are similar to those faced by traditional land-based fertilizer applications or current state-of-the-art aerial application systems. Fertilizers should not be applied during rain or wind events because fertilizers can be blown or washed away from the desired locations, leading to waste and eutrophication. Unique to UAV-based systems is an increased sensitivity to wind, with even mild gusts limiting the ability to fly UAVs. One benefit of aerial systems is that fertilizer can be applied after a rain event without increasing erosion or impacting soil health. These are consequences of driving tractors over waterlogged soil.

2.8. Expected Improvement

The predominant method for determining when fields need fertilization is soil sampling, subjective color ratings, and in some crops, chlorophyll meters. For accurate representations, many samples should be taken; however, this can be labor-intensive. Subsequently, this may lead to poor sampling. Farmers also utilize predetermined rates based on university recommendations or personal experience. This method may lead to under- or over-fertilization, which poses the same risks for inaccurately predicting the required amount of fertilizer.

State-of-the-art UAV-based remote sensing and fertilizer application systems are only used sparingly because they require significant data processing between the remote sensing and fertilizer application phases. Users of these systems often perform remote sensing one day and process the data overnight before applying fertilizer the following day, making the process time-consuming. Additionally, weather conditions may also delay applications due to wet soil conditions or, in the case of UAVs, high winds.

Under the proposed PRECISE system, these drawbacks from traditional land-based fertilizer or UAV-based applications would be alleviated. Simultaneous remote sensing and spraying operations would enable same-day sensing and fertilizing at a variable rate to prevent over- or under-fertilizing. The relative ease of the system may encourage more farmers to switch to aviation-based variable-rate fertilizer applications, which would have significant environmental benefits.

2.9. Interoperability with existing systems

Currently, the most widely used UAV-based systems provided by DJI technology require users to upload their data to Chinese-based servers which risks becoming restrictive due to government policies. The PRECISE system would eliminate the need to upload user data to foreign servers, increasing access to UAV-based remote sensing and fertilizer applications to more users while ensuring cybersecurity of geospatial data. Additionally, the system could be adapted to use existing or new UAV hardware that an individual user may have or be modified for use with different fertilizers, herbicides, or pesticides as needed.

3.0. Pathway to implementation by 2035 and future perspectives

The pathway to deploy the PRECISE system by 2031 is laid out in *Figure 3*. In addition to developing PRECISE's software and conducting calibration studies, improvements in biochar-based fertilizer are needed. The current cost of producing biochar-based fertilizer is high. Infrastructure needs to be established to reduce this cost. Once PRECISE is readily available and the need for more sustainable agricultural practices outweighs the traditional practices, the market will have a higher demand for sustainable agricultural products, including biochar-based fertilizer. Additionally, the cost savings of PRECISE VRA will motivate growers to adopt biochar-based fertilizer faster.

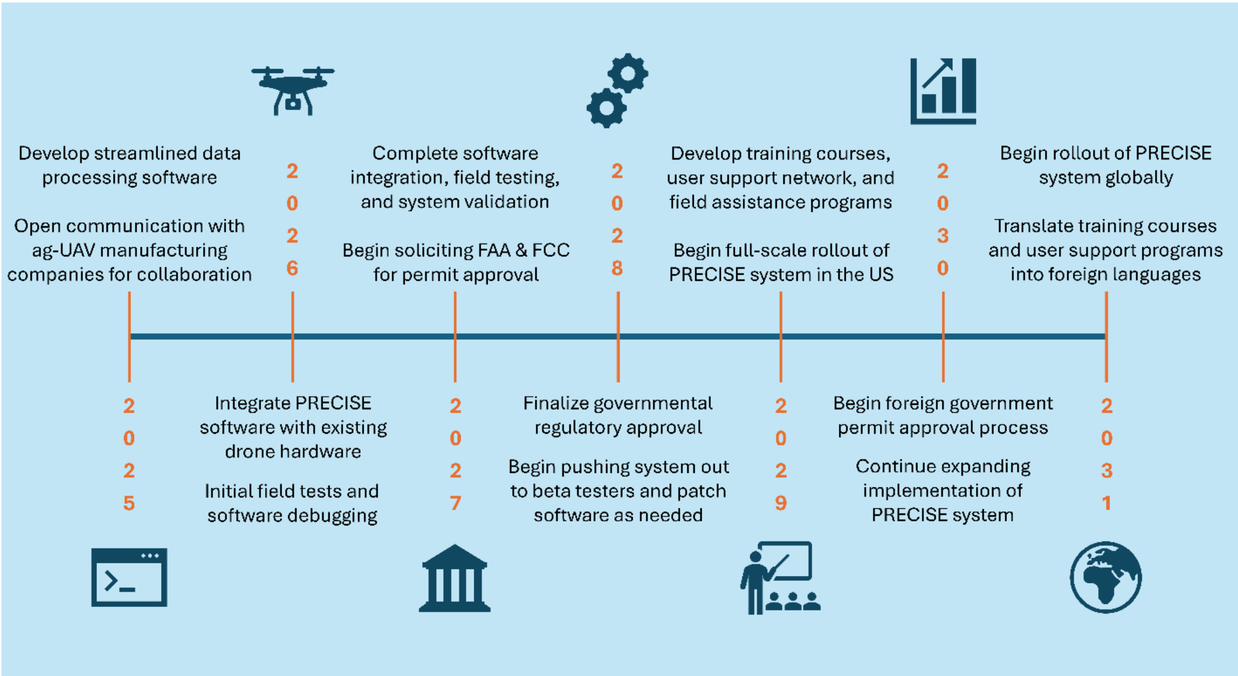

Figure 3: Pathway to PRECISE deployment by 2030

3.1. Training

Training for the PRECISE system could be through in-person sessions or online tutorial videos. Users need to be familiar with how to physically set up the UAVs, including changing and charging batteries, filling the spreader UAVs' hopper or tank, and maintaining the UAVs. Users would also need training in using the command station software's graphical user interface (GUI), including delineating field boundaries, preset application rates, and other user-defined parameters, and indicating no-fly zones for the UAVs. Real-time support would also need to be provided via online chat or phone call to help users troubleshoot challenges as they occur.

3.2. Customer-Stakeholder Operational Integration

It presently takes 6 and 8 months for an individual to receive their UAV certifications and complete other FAA procedures to have permission to operate a UAV. The PRECISE system must comply with all federal and state regulations so that individuals can safely and legally operate UAVs for agricultural purposes.

3.3. Opportunity Barrier Analysis

The proposed system uses existing technological capabilities in an innovative and impactful way. The system would require control systems for the two separate sensing and spraying UAVs to be hardwired together (or combined in the same unit), a task that is well within the realm of possibility and would need to be completed. Additionally, new software packages for use on both the UAVs and the user interface will need to be developed to allow the sensing UAV to convert multispectral data into application rates and for users to visualize this via the control system.

A federal policy was just changed that enables individuals to fly more than one UAV simultaneously with a proper exemption (44807) that will remove policy barriers from preventing the implementation of the system (Federal Aviation Administration, 2025).

The most considerable tradeoff of the system is that less data will be collected than by current agricultural UAV systems. While this enables the PRECISE system to perform remote sensing and spraying simultaneously, some accuracy may be lost, and there would be a limited mapping of the spray rate only, not complete spectral data.

4.0. Conclusion

Implementing a PRECISE technology system that provides real-time, targeted fertilizer applications signifies a crucial development in sustainable agriculture. This approach improves crop health and output by promptly addressing nutrient deficiencies and applying only the requisite amount of fertilizer, thereby minimizing waste and environmental harm. This degree of precision is crucial for modern agriculture, where the optimal utilization of resources is vital for sustaining profitability and reducing ecological impact. In contrast to traditional systems restricted to specific inputs, it can function with any fertilizer, encompassing novel, eco-friendly alternatives such as biochar-based fertilizers. Biochar enhances soil structure and nutrient retention while acting as a long-term carbon sink, aiding in carbon sequestration and climate mitigation. The advantages of biochar are optimized when combined with precise application, providing optimal nutrient utilization and minimal emissions.

This fusion of aerial monitoring and innovative application transforms how and when fertilizer is delivered, enabling farmers to make timely interventions without labor-intensive scouting or heavy machinery. Especially in extensive or remote agricultural operations, this significantly reduces time, labor, and fuel costs. The system provides evident economic value. Minimizing excessive application, decreasing maintenance expenses, and enhancing long-term soil vitality reduces the overall cost of cultivation. Furthermore, incorporating biochar facilitates access to carbon credit options, providing farmers with an additional money source while promoting sustainable practices.

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