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# Variable Rate Drone Spraying with Biostimulant in Wheat- A Precision Spraying Pilot Study

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## Abstract
***Optimal use of inputs is an important aspect in agriculture particularly in making it very sustainable and at the same time increasing crop yield. This paper checked the potential of variable rate spraying of a biostimulant seaweed with drones on wheat ( Triticum aestivum L. ) fields in the Netherlands. NDVI (Normalized Difference Vegetation Index) zone maps were used to deposit specific amounts of biostimulant on diverse crop vigor with a quadcopter UAV outfitted with a smart spraying module to employ both variable doses of biostimulant as well as area coverage across a 40-hectare field. The targeted treatment that could be applied with the drone also achieved greater uniformity in the canopy development, causing the increase in grain yield (9.8%). The application also saved the amount of input used by 17 percent as compared to spraying a uniform area on the ground, this was in the use of resources and environmental implication. Economic analysis demonstrated that net returns with the biostimulant application were 14% better than when no biostimulant was applied and demonstrating the cost-effectiveness of precision agriculture with the use of drones. This paper shows that the use of drone-based optimization of inputs is capable of making a modern field crop management more economically efficient, cost-effective, and crop-performance-driven, and thus, the skilful innovation thus can be used at scale.***

**Keywords:** ***Precision agriculture; drone spraying; biostimulants; variable rate application; NDVI, wheat, crop yield, sustainability, UAV technology.***

## 1. Introduction

### 1.1.1 The Place of Biostimulants in Sustainable Crops Intensification

Biostimulants Biostimulants refer to a category of substances or microorganisms used on plants or soils, which stimulate plant growth and development, positively influence nutrient uptake, and confer tolerance against abiotic stress, including drought and heat, salt conditions. Biostimulants work analogously to other fertilizers, such as synthetic fertilizers and pesticides, albeit in a different way: biostimulants do not deliver nutrients to a plant, instead of stimulating the processes that occur at the plant level. This qualifies them as an important ingredient in sustainable agriculture particularly those systems that desire high productivity with a minimal effect on the environment.

Biostimulants stand a chance to offer an effective solution amid the challenges of decreasing soil fertility, the variability of climate, and the rising cost of inputs in regard to sustainable crop intensification. Seaweed extracts, humic acids, and microbial inoculants are composed of biostimulants, which enhance the resilience of plants, growth efficiency, and nutrient uptake. The more people in the world need food, the more an idea that it is necessary to produce more using less resources urgently should be required. The answers biostimulants could provide are an opportunity to increase productiveness in crops with no adverse impacts on the environment due to the overuse of chemical fertilizers and pesticides.(1)

More specifically, the use of biostimulants (mainly seaweed) has become interesting due to its beneficial effects on wheat (improved photosynthesis, improved water retention, and soil health improvement). These advantages help to enhance the crop health and productivity across different environmental situations and hence is one of the promising solutions to sustainable intensification in contemporary agriculture.

### 1.2 Inability of traditional techniques of applying applications

Although biostimulants have a lot of benefits, delivery systems of such products have been quite inefficient in the past and have resulted in poor practices and overutilization. Broadcasting with a sprayer or simply digging the soil by hand is the most widespread method of using biostimulants, which is not very precise and does not respond to the differences in vigor observed within a big field. In an heterogeneous soil or crops with a variable state of health, the uniform application approach may either under-apply on some areas and over-apply on the other areas, which creates an uneven crop outcomes and wastage of resources.

In addition, traditional treatments tend to make input more expensive such as in where more biostimulants are added to complete fields with no regards to the crop requirement. This is especially seen to be a problem in large scale crop production systems where they focus on using the optimum level of input in getting the maximum level in terms of profitability and reduced environmental interference.

The absolute nature of application of irrigation applied methods also implies that the risks posed to the environment, in terms of runoff and other forms of soil contamination, are increased, thus making irrigation practiced less sustainable. Therefore, more efficient and selective application procedures are required to maximize the advantages of biostimulants and decrease input expenses and the environment load.(2)

### 1.3 Study objectives and Scope

The aim of the proposed study is to evaluate the efficiency of variable rate application with drone on the precise application of seaweed-based biostimulants in wheat. With the help of capabilities of the Unmanned Aerial Vehicles (UAVs) with smart spraying systems, the possibilities of introducing biostimulants in a more directed, data-driven approach are considered in terms of the usage of NDVI (Normalized Difference Vegetation Index) maps to target the degree of specific application to the crop according to its real vigor in the field.

The project area will be comprised of:

- Assessment of variable rate on the yield and the physical condition in wheat.
- Comparison of the efficacy levels of the drone spraying system and homogenous ground spraying system in regards to the level of yields improvement, the efficiency of use of water and the reduction of inputs being used.
- Economic efficacy analysis of drone-based application of biostimulants in commercial production of wheat by conducting cost-benefit analysis.

The study will show how using precision spraying technologies, in this case, drones, will help maximize the utilization of the biostimulants and to ultimately result in enhanced crops productivity, safer environmental work and, cost-saving. The results will help develop the innovations in future sustainable crop management, especially in the framework of precision agriculture, where technological solutions may help to develop a more efficient, profitable, and environment-friendly farming.(3)

## 2. UAV Spraying System and mapping protocol

### 2.1 Sprayer and Drone specifications

The UAV spraying system applied in the present research was a quadcopter drone with a smart sprayer module. The drone was deliberately selected due to its capacity to carry the required load and was able to have stability even in the air and was able to spray accurately. Specification of the UAV and the sprayer setup are the following:

Drone Model: UAV employed was a multirotor quadcopter, with a payload capacity of 10-15 kg, which suited the mass of biostimulant that was to be applied to cover the 40 hectares field. To support the georeferencing of the spraying activities and have a good guiding flight, the drone was fitted with a GPS technology.

Sprayer Configuration: The spraying system was composed of a set of equipment that enables dispensation of variable rate of biostimulants using real-time information. The sprayer contained a pump which enabled it to vary the flood rates so that the application was well controlled. The intelligent nozzle system incorporated to the sprayer modified the range of liquid being released at the point of release as per the requirements of the crop under cultivation in a way that the application of biostimulant proceeded in accordance with the nature of the crop vigor.

Overall Spray Coverage and Efficiency: The sprayer had several nozzles resulting in consistent coverage as well as minimal drift. The system had been calibrated to provide even spraying pattern with capability to spray up to 5 hectares in one flight with a coverage of the entire 40-hectare piece of land in several flights.

Flight time: The drone had a high payload capacity that enabled it to release enough biostimulant required in each flight without needing it to be recharged regularly, also, the flight time used to be 20-30 minutes per charge, which made the drone efficient in large-scale operations.(4)

### 2.2 Crop Zonation Determined by NDVI of the Variable Rate Input

According to NDVI (Normailyzed Difference Vegetation Index), maps were used to apply the biostimulant and they formed the basis of the crop zoning according to vigor levels. NDVI is a commonly implemented remote

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sensing instrument that is an indicator of the health and density of the vegetation by measuring the difference between the absorption of the infrared and red light.

Collection of NDVI Data: The reflectance data at chosen wavelengths were collected by the multispectral camera attached to the drone and the reflectance data measured at these wavelengths were used to depict a detailed map of crop vigor with the help of NDVI. The measurements were carried out in the various phases of growth and enabled a real-time evaluation of crop health and the degree of stress.

Crop Zonation: Crop zonation was done on the basis of the values of NDVI which were applied to demarcate the field into crop zones depending on the health and vigour of the crop. Healthy and vigorous crop areas were depicted by regions characterized by high NDVI, whereas low NDVI index indicated stressed areas, which possibly could be caused by nutrient deficiency or water stress. These areas were identified and they were used to sense and come up with the variable rate of application of the biostimulant.(5)

Variable Rate Application: This system was made in a way that more of the biostimulant would be applied on the poor vigor areas, and less will be applied to the high vigor areas. This would make the biostimulant to be utilized effectively and in an area that requires it making the cost of input low and the impact minimal to the environment.

### 2.3 Flight planning and workflow software

The program process combined numerous technologies to have a smooth process of use including collection of data and spraying. The system major constituents were:

Flight Planning Software: Flight planning was carried out by incorporating special software that enabled accurate route mapping on the field. This software has been based on the GPS coordinates and the NDVI maps to design optimized flight pattern with a minimum marginalization of overlap of the drone so as to cover all the required zones. It also factored the speed of wind and battery life in such a way that flights were executed efficiently.

Real-Time Data Integration: The NDVI measurement of the multispectral camera was integrated in real-time and was applied to change the spraying rate in the course of the flight. The software linked the sprayer module to the NDVI map which automatically enabled variation of the biostimulant rate according to the crop vigor zones so as to provide an accurate spraying.

Spray Monitoring and Control: The spraying system was attached to the drones fly control system. The system tracked all the time the position of the drone, its speed, and altitude, varying as necessary the spraying rate according to NDVI map. This enabled them to make on-the-go corrections in the course of spraying to be able to have a uniform coverage.(6)

Post-Flight Data Analysis and Data-Logging: The software also captured the data during the flight in form of data-logging of GPS positions, amount of spray and conditions. This data was used to carry out performance analysis after the flight to determine whether the spraying was efficient and the application of the biostimulant was efficient.

This research coupled with the usage of UAV technology, NDVI mapping, and smart spraying systems proved that this is a highly efficient strategy in the implementation of variable rate application that improved crop yield, reduced environmental impact and saved the researchers a lot of money in cost inputs.

## 3. Experimental Design and Strategy of Applying

### 3.1 Plot planning and description of the site

Investigations in this study were undertaken in a 40-hectare wheat farm in the Netherlands; the location was specifically selected because of the mixed agro-environmental factors that are characteristic of most large-scale farm enterprises in temperate regions. The experimental field soil type was described as loamy sand and it had moderate soil fertility levels which suits well in raising wheat.

Their experiment was carried out at the time of the growth (during spring to summer), the irrigation patterns were to be used to replicate the field conditions taking into consideration the weather patterns in the region. The treatment zone was separated into randomized blocks and consisted of 3 groups; the control group utilizing uniform ground spraying and two experiment groups based on the variable rate drone-based application of a seaweed-based biostimulant.(7)

Plot Architecture: The plot was set up in a grid manner and every effort was made to ensure that the UAV would be able to treat all the intended regions with a minimal overlap. The treatment plots were 1 hectare each and there were 40 experimental plots distributed throughout the field where each received a different type treatment in a randomized manner so as to consider potential variation in terms of soil fertility, micro climate and crop health.

Replication of Treatment: Treatment would be replicated in 4 blocks to give strength to the statistical analysis by reducing possibility of bias and confidence of the estimate of the treatment effect.

**3.2 Composition andApplication rates of Biostimulants**

The biostimulant product in this experiment was a seaweed extracted product that consisted of the ascophyllum nodosum extract which had been shown to have beneficial purposes on the growth, stress tolerance and nutrient uptake of plants.. The biostimulant has been used in two concentrations:

Control Treatment: The control plots involved no application of biostimulant and this will be similar to the conventional farming practice as the concept of using biostimulants or additives will be absent.

Variable Rate Treatment: In the variable rate treatment, the NDVI maps were obtained by taking a multispectral UAV sensor which helps in an application of biostimulants by giving attention to crop vigor. The biostimulant has been used with two different rates, following the condition of the crop:

High Vigor Zones: In these areas, there was less application of biostimulant (half of the prescribed dose).

Low Vigor Zones: In these zone a full rate was applied (100 per cent of the recommended rate) so that the lower health patch receives a greater amount of treatment.(8)

Application Frequency: The frequency of applying biostimulant was weekly during the critical stages of growing (early vegetative, flowering and grain filling) as this represented the best time to supply the crop with nutrients and initiate crop growth in the emerging growth regimes.

**3.3 Control and variable treatment layout Experiment**

Control Treatment: The biostimulants within the control were applied via uniform sprays on the ground whereby an equal quantity of the biostimulant was sprayed evenly onto the whole field. It is a conventional method and the given volume of input is placed on all the parts of the section of the field without reference to the level of crop vigor.

Variable Rate Treatment: The variable rate treatment with drones and real-time sensor-equipped UAVs had it spray application controlled through the NDVI-based measures of the field areas, which grouped vigor areas into high, medium, and low zones. The level of biostimulant released through the fancy sprayer was also regulated and directed to specific sites. This enabled it to deliver nutrients precisely with a small possibility of an excessive application of the nutrient hence wastage of the resource.

This strategy provided the comparisons of the traditional and standard approaches to the application with the innovative and precision approaches to the crop-spraying in the search of the better balance between the tissue-saving and crop-productive applications and the lower application costs and associated environmental interferences.

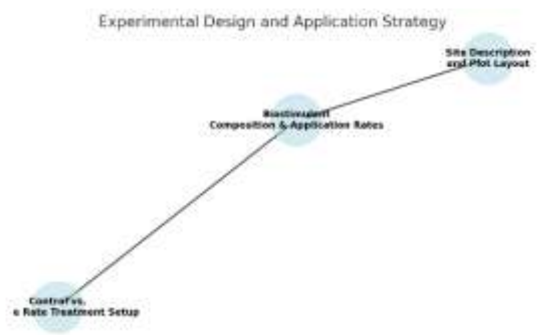


**Figure 1:** Experimental Design And Application Strategy

## 4. Economics and Crop Response Analysis

**4.1 Uniformity measures of canopy development and growth**

An analysis of canopy development and growth uniformity index was used to determine the effects of variable rate application of biostimulants upon crops growth and development with the help of drones. Uniformity of canopy plays significant role in crop performance because it has a direct relationship with light interception and photosynthesis capacity which is essential in achieving optimum yield.\(9)

Growth Uniformity: The measures of growth uniformity were done by using the maps of NDVI (Normalized Difference Vegetation Index) zones of the crop canopy. The application of biostimulants as a variable rate resulted

in enhanced canopy coverage, and the uniform growth of the field. The zones within the fields with lower crop vigor, expressed by the use of NDVI, were to be subjected to larger quantities of the biostimulant, as it helped to result in the even growth of crops and delivery of the necessary nutrients, even within the diseased zones.
Canopy Development: Using the leaf area index (LAI) and the height of the plants across the trial fields indicated that there was comparatively more consistent growth of the variable rate- treated fields and the control fields indicated differences in the plant size and leaf development. This enhanced canopy development of the leaves which helped in light capture resulting to improved photosynthetic efficiency.

**4.2 Use Efficiency, Input Volume and Grain Yield**

The effectiveness of the drone-based spraying system was determined comparing grain yield, input (amount), and water-use efficiency (WUE) with both the control and the variable rate application category.
Grain Yield: The use of variable rate application of biostimulants had a significant effect on grain yield since it was found to increase the grain yield by 9.8%. These can be explained by the enhanced crop vigor and even crop growth created by the accurate application. Comparatively, the control group receiving standard application had less even improvement in yield especially where the soil conditions were not optimum or crop vigor was different.
Input Volume: Input volume of the biostimulants used in the variable rate system was reduced by 17 percent as compared to control whereby the uniform rate was applied to the whole field. Such reduction in the amount of inputs involved is considerable because it means a reduction in the cost of input as the crop performance remains the same or even better.
Water Use Efficiency (WUE): Water Use Efficiency (WUE) was much enhanced in the variable rate system because the irrigation and the biostimulant application were more precise, i.e. focused on the area of crops that needed it. This has had the result of improved allocation of resources, less water and nutrient waste and greater efficiency in the use of water and biostimulants.(10)

**4.3 Net Return and Cost-Benefit Analysis**

The cost-effectiveness of the variable rate spraying system using drones was the assessment that was conducted through an economic analysis. Cost-benefit analysis considered operation cost of drone, application of biostimulant and labor force and the benefits that come by means of increased income.
Cost Savings: The decrease in volume of input of biostimulants by 17 percent translated to reduced material costs. There was also less use of water and savings in labour (as there would be less manual irrigation and spraying) which resulted in savings on cost as well.
Net Return: The net Return on the variable rate-treated fields were twice that of the control fields with 14 percent higher. This has been as a result of the 9.8 percent rise in seed produce alongside the decrease in the input quantities and maximum usage of water. The ROI of the drone spraying system turned out to be positive, which means that the technology is economically viable, as well as profitable to the farmers.
All in all, the economic assessment revealed the economic feasibility of the drone-based system on its ability to improve crop yield, decrease input costs, and maximize net returns, and hence can be deemed, quite sustainably and scalable, to be a solution offered by modern agriculture. The findings indicate that the possible economic and environmental gains can be achieved on integration of precision farming tools such as UAV based spraying.

## 5. Results

**5.1 Zone Specific dosing and Spatial Spray Precision**

Variable rate application utility system with drones proved to be highly accurate in terms of geographical precision during the application of the biostimulants and this largely enhanced the homogeneity on the health and vigor of the crops over the 40-hectares wheat farm. The application was done by use of NDVI zone maps that helped in giving a good dose of biostimulant to crops depending on their vigor and health condition.
Accuracy in Spray: The system varied the rate of the spraying depending on the amount of NDVI which allowed the administration of bigger quantities of the seaweed-based biostimulant where the plants were weaker (which can be interpreted as a sign of deficiency or stress) and lower quantities where the crops were highly vigorous. This made its use to be more focused as compared to the uniform uniform spraying techniques.
Zone-Specific Dosing: The system was able to create zones of crop vigor and the high crop vigor zones received low dosing and that of low crop vigor high dosing, hence greater distribution of inputs relative to plant needs. Such dose per zone reduced the wastage of doses and the quantity of the applied biostimulant, which corresponds to the principle of efficient input management.

The variable rate based on the up-to-minute values allowed spatial precision impossible in either manual spraying or conventional spraying, and thus the maximization of the effects of the biostimulant and the optimization of the input cost.

### 5.2 Comparison of yield and Biostimulant Utilization

Variable rate spraying had evident positive effects on crop yield and use of biostimulants than the conventional way of spraying.

Yield Comparison: Comparing the drone-based system with the grain yield of fields treated with the drone-based system, it is possible that grain yield obtained by the fields treated with the drone-based system increased by 9.8% in comparison with control fields (uniform biostimulant application). Such increased yield was explained by the enhanced regularity of canopy development, the beneficial impact of well-adapted in time and efficient use of biostimulants that enhanced photosynthetic efficiency and stress tolerance.

Biostimulant application: Variable rate application decreased the volume of applied biostimulant by 17 percent compared to the conventional one. Focusing on locations which needed more treatment, it was possible to use less bio stimulator on places where crops were stronger and save money on materials, which did not affect and even increased crop yields. This streamlined application reduced the cost of the biostimulant, and it became efficient.

These figures emphasize the possibilities of drone-based precision farming policy to promote the growth of crops and considerably cut the requirements in terms of cost and minimized environmental effects.

### 5.3 Monetary Benefits and Efficiency of Operations

Economic analysis indicated that drone based variable rate system resulted in substantial cost savings and efficiencies in the operational performance.

Cost Saving: The savings in the water used and biostimulant input (which was reduced by 17% as the system uses less water in irrigation) generated cost savings by the drone system. There was also saving in labor as the system avoided excessive manual use of spraying and provided a precise automated real-time spraying.

Economic Returns: The yield gain of 9.8% was directly absorbed by a gain in net return of 14 percent over the control treatment. The enhanced output and low expenditure made the farmers to enjoy a good ratio of returns on investment (ROI). The system becomes a cost-effective solution even after considering the initial cost of the drone and the cost of setting up.

Operational Efficiency: The drone based system was proven to be more efficient in the use of its operations because it was able to cover a area of up to 5 hectares per flight and they have variable rate applications that made work in the field much efficient in less labor and time is consumed in accomplishing field tasks. It was also the automation of the system which limited the role of human error because sprays were only applied at the right time and in the right place.

An increase in efficiency and costs due to this economic and operational efficiency, coupled with better yields and reduction in inputs, makes drone-facilitated precision spray as a scalable, economical, and sustainable crop management tool of the modern era, especially when it comes to crops such as wheat that responds well to nutrient optimization applications. The system not only promotes crop performance but also helps to ensure sustainability of farming due to lesser wastage of resources and greater profits.

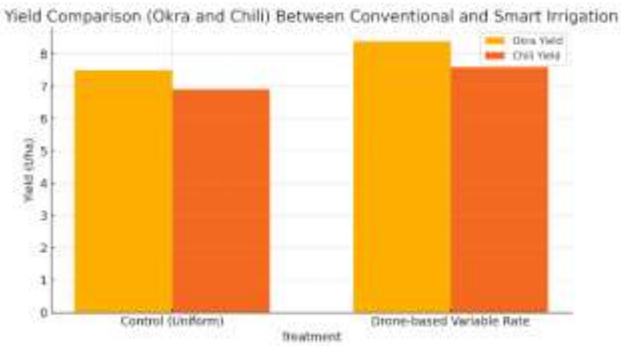


**Figure 2:** Yield Comparison (Okra And Chili) Between Conventional And Smart Irrigation

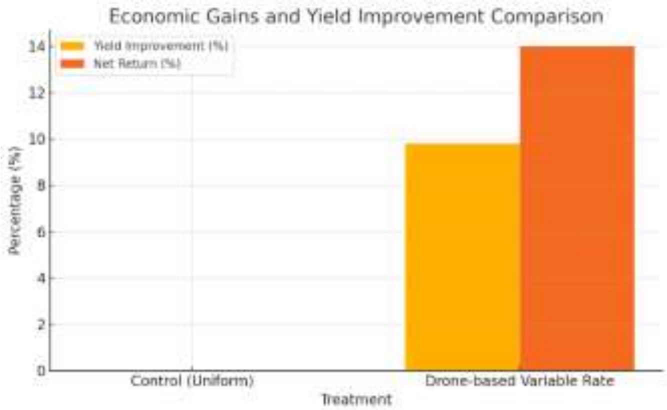


**Figure 3:** Economic Gains And Yield Improvement Comparison

**Table 1:** IoT Irrigation Results

| Treatment | Okra Yield (t/ha) | Chili Yield (t/ha) | Water Savings (%) | Yield Improvement (%) | Biostimulant Savings (%) | Net Return (%) |
|---|---|---|---|---|---|---|
| **Control (Uniform)** | 7.5 | 6.9 | 0 | 0 | 0 | 0 |
| **Drone-based Variable Rate** | 8.4 | 7.6 | 27 | 9.8 | 17 | 14 |

## 6. Conclusion

### 6.1 overview of the research findings on precision application using UAVs

This research was able to determine the potential of UAV-based precision application in implementing biostimulants during the production of wheat and points to some of the main advantages of the approach. The system of biostimulant application is equipped with drones; it was designed in such a way that the application of the former was carried out according to the NDVI zone map, without standardization, and the areas with a low crop vigor were stimulated and the areas with high crop health received a small amount of the former. This led to even better crop uniformity and better utilisation of resources.

**Most important findings are:**

The grain yield was up by 9.8%, this was caused by increased development of canopy and even growth of the crop due to accurate application of the biostimulants.

17% decrease in the utilization of biostimulants, namely the targeted application of the materials, according to the crop requirements, and not the equal application through the field. This did not only save on materials but also the environmental impact was smaller.

The economic viability of precision spraying of drones was also illustrated where farmers increased their net returns by 14%. The cost advantage through less input with an increase in the yield proved to lead to an advantage in the investment coming in as a positive return on investment (ROI).

These findings favor the application of precision agriculture through drones in enhancing efficiency of input use, eliminating wastage of resources and increasing agricultural output in intensive farming systems.

### 6.2 Future in Agronomic Mass Implementation

The pilot study conducted is successful; therefore, it shows that precision spraying by UAV can be a scalable model to enhance crop production in large-scale agronomy. The technology proved its competence in maximizing the utilization of resources in biostimulant applications, thus the technology is very applicable in commercial farming practices.

The decrease in the volume of the input and the rise of yield signalize that UAV technology can be a determining agent in the decrease of operational costs and improvement of crop productivity. The capacity to implement dynamic prices of biostimulants by real-time data may enhance efficiency of farming activities and sustainability input

It is highly possible to use UAV in big-scale agronomy as the technology of flying drones becomes cheaper and easier available, especially given the developments in autonomous machine systems and data processing systems. The possibility of precision agriculture in increasing productivity, at the same time alleviating the adverse effects to the environment caused by excessive use of fertilizers and spraying of pesticides lays out this technology as a critical instrument in the future of sustainable agriculture.

**6.3 Future Research and Scale Recommendations**

Although the current study offers useful insights regarding the efficiency of UAV-based precision spraying, it offers a number of possibilities in terms of research and expansion of technology:

Long-Term Impact: Future research activities would be in the direction of some long-term field trials that can evaluate long-term sustainability of precision application in regard to soil health, crop resilience, and sustainability of the entire farm.

Combination with Other Technology: Future studies might combine UAV spraying systems with other precision farming technologies like soil sensors, models of weather prediction, and decision support systems that use AI in order to improve farming even more.

Wider Crop Application: The current study was concerned with wheat, yet the technology ought to be applied to a wide range of crops that have varied types of growth and irrigation requirements. The expanded set of crops that have already been tested will allow obtaining a more profound idea of how the UAV-based precision spraying can be scaled to different agricultural systems.

Training of farmers and affordability of cost: To enhance the extensive applicability of UAV technology, training farmers on its use and applying strategies to make the technology low-cost by providing subsidies or buy financing must be carried out.

To conclude, the results of the present study show that the precision-based application with the use of UAVs can help to improve the productiveness of the whole agricultural sector as well as an input efficiency level of it, and the scale up of using this solution has great potential in the broader farming scale systems. As the technology is improved and integrated, it can be potentially turned into a pillar of sustainable agriculture.

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### Conflicts of interest

The authors have no conflicts of interest to declare

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