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THE USE OF DRONES IN PRECISION AGRICULTURE: A REVIEW

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ABSTRACT

The use of drones in precision agriculture has become a revolutionary tool in the agricultural sector, due to its ability to optimize processes, increase productivity, and reduce costs, while promoting more sustainable practices in the field. Given this scenario, this article aims to describe important aspects in the use of drones in precision agriculture. To achieve the proposed objective, a bibliographic survey was carried out, searching, through the CAPES and Scielo journals, articles published in the last 5 years, whose theme was the use of drones in precision agriculture. From the results, it is evident that the use of drones in precision agriculture is promising, with increasingly larger projections in Brazilian crops. This result reflects important aspects among the benefits of this resource, which is the reduction of time and costs for the producer, which, consequently, increases crop productivity.

Keywords: Agricultural sector, Agribusiness, Technology, UAVs.

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INTRODUCTION

Since its beginnings, agriculture has been essential for the survival of humanity and for this reason it has developed over time, following the evolution of man. In the face of global challenges, such as the growing demand for food, climate change, and the need to conserve and preserve natural resources, technological advances in agriculture are essential to increase sustainability and productivity.

From this scenario, Precision Agriculture (PA), that is, a modern approach that uses advanced technologies in the agricultural area, comes as a great ally to optimize the use of agricultural resources. Thus, with the growth of the agribusiness sector, the country needs technologies that increase agricultural production, and PA emerges as a watershed in Brazilian agriculture.

It is noted that with the advancement of technologies, Precision Agriculture tends to be increasingly consolidated in rural properties. Current technological solutions already allow a deep knowledge of the variabilities within the production areas, enabling decisions to be made based on more reliable and accurate data.

Thus, one of the great promises of precision agriculture is the use of UAVs (Unmanned Aerial Vehicles), popularly known as drones, which are already being widely used for monitoring crops, identifying plant health, such as nutritional deficiencies, failures, pest infestations, through high-resolution multispectral images, in addition to other uses that improve agricultural management.

In this sense, many researchers claim about the ability of UAVs to collect data in real time and provide accurate information about the crop, allowing farmers to make more effective decisions, based on concrete data, reducing waste and increasing crop productivity. With high-resolution cameras and advanced sensors attached, drones are also used to spray pesticides, carry out topographic mapping and soil analysis, optimizing agricultural management.

For farmers, the relevance of the topic lies mainly in reducing the unnecessary use of inputs, such as fertilizers, in areas that do not need correction, reducing planting costs and obtaining greater knowledge about the soil and the production environment. Therefore, the analysis of the benefits of precision agriculture with the use of drones is important, since this method, although promising, is still relatively new and little explored in agribusiness.

However, there are issues and challenges that need to be addressed in the use of drones, such as ethical issues associated with the massive adoption of this technology, such as privacy and security, flight regulations and legislation, and climate and geographical limitations.

Another important situation in the use of drones is in relation to the technical knowledge to operate and do the proper data analysis, as the use of this equipment requires the use of specific software and technical knowledge about it. In addition, it is necessary to highlight the socioeconomic issue, considering that the acquisition and maintenance of drones equipped with advanced sensors and high-resolution cameras, the capacity and qualifications of professionals to operate it and interpret the results, can represent a high investment, becoming an obstacle, especially for small farmers.

Based on these premises, this article was intended to carry out a literature review study that aims to establish an analysis of the use of drones in agriculture. Thus, this article aims to describe important aspects in the use of drones in precision agriculture.

THEORETICAL FOUNDATION

PRECISION AGRICULTURE (PA)

Brazil is considered the country with the greatest agricultural potential in the world. And, it is not by chance that the agribusiness sector is of great importance to the Brazilian economy, as it is in this activity that about a third of the country's income is available. Pena Junior and Françozo (2023) believe that the success of Brazilian agribusiness is directly related to the increase in agricultural production and productivity, as a result of the implementation of new technologies in the cultivation and management of crops. These innovations have optimized the use of resources, improved the efficiency of production processes, and allowed the country to stand out as one of the world's largest producers in the field of agriculture.

In view of such economic and social importance of agricultural activities, also considering the growth of agribusiness, it has become essential to manage its production processes, in addition to investing in technologies that can improve factors that influence production, such as soil fertility, topography and climate, taking into account that each portion of the crop needs specific management to optimize productivity. According to Puschi, Machado and Amaral (2019), this way of doing agriculture, taking into account the specificities of each plot of crops is called Precision Agriculture (PA).

The term Precision Agriculture has several definitions made by various researchers and scholars in the area. However, the basic concept is that crops are not invariable, requiring forms of management that investigate these differences found in each field, taking economic advantage of it (MENDES, 2019). For Molin (2002), Precision Agriculture consists substantially of a system of administration or maintenance of agricultural production that

concentrates a set of technologies and procedures so that crops and production systems are enhanced, based on the management of production variability and the factors involved.

In general, precision agriculture is the set of techniques and procedures that allows to know, geographically locate and delimit areas of different productivity, through the use of computers, specific programs, sensors, machine controllers and global positioning system (GPS). In this way, precision agriculture is a tool that helps producers in making managerial decisions in crop management, taking into account the spatial and temporal variability of the crop to obtain maximum economic return and reduce environmental impact

According to Mendes (2019), precision agriculture involves the use of advanced technologies for the efficient management of soil, inputs, and crops, adjusting to spatial and temporal variations that influence productivity. This new agricultural approach is driven by remote sensing, geographic information systems (GIS), and global positioning systems (GPS). Together, these tools allow for more accurate and sustainable crop management, optimizing resources and improving agricultural yield.

It is worth mentioning that, according to Molin, Amaral and Colaço (2015), in the beginning, the concept of precision agriculture was linked to the tools for georeferencing data in crops, such as GPS, for example, which for a long time generated mistaken definitions for PA. It is now understood that precision agriculture is a crop management methodology, which in addition to optimizing productivity and reducing expenses, brings positive gains to the environment, as it has sustainable characteristics at its base (Mendes, 2019).

In other words, precision agriculture is an agricultural management philosophy that takes into account spatial and temporal variability to manage inputs and optimize crop productivity and profitability, in addition to being based on sustainability. On the other hand, in relation to conventional systems, it is noted that as they do not respect the specificities of the soil portions, it generates inadequate management, harming the environment and making production more costly.

In summary, precision agriculture promises to reverse the current situation by allowing the application of agricultural inputs in the correct places and in the required quantities. Therefore, the main objective of Precision Agriculture (PA) is to mitigate planting costs for rural producers, and thus increase crop productivity, thus bringing producers the chance to improve their techniques and forms of management to achieve better results.

As already mentioned, precision agriculture has relied on the high technology of agricultural drones in recent years, offering new possibilities for monitoring and managing crops in a more efficient and detailed way. This new technological resource has been

gaining prominence on large properties and is projected to become increasingly fundamental in precision agriculture. Its high-tech sensors, integrated multispectral and infrared cameras promise to revolutionize agribusiness.

UAVs

According to Castro (2019), unmanned aerial vehicles (UAVs), popularly known as drones, are remotely controlled aircraft. In general, it is an aircraft that can be moved in all directions, controlled in the 3 axes, without the need for an onboard pilot. The drones have the appearance of mini-helicopters, which receive command by radio frequency, infrared or GNSS (Global Navigation Satellite System) coordinates.

According to Itarc (2018), the first UAVs appeared in the 1960s for military purposes, but only in the 70s and 80s did they start to be used in espionage and surveillance missions. These vehicles were used as a strategy for reconnaissance of terrain, allowing an aerial view, by military personnel in the United States and the Soviet Union, in the Cold War period, undergoing significant advances becoming known worldwide.

However, although drones were initially developed for military use, their functions were reformulated, becoming a very stable technology and currently, their civilian applications are numerous and operate in the most diverse sectors.

One of the sectors that have used these unmanned vehicles to optimize their services is agriculture. According to Oliveira et al. (2020), UAVs have become essential tools within precision agriculture due to their potential for territory recognition, working in the process of extracting information from areas. The authors also state that due to the great demand of the agricultural sector and the need for technological development, drones are tools that are projected to be increasingly present in rural production activities, as they are capable of monitoring crops in real time and with greater detail of characteristics, in addition to other uses, which help reduce producers' time and cost, consequently optimizing processes, whether in large or small crops (Oliveira et al, 2020).

In this scenario, among the main ways of using drones in agriculture, the following stand out: monitoring and mapping of cultivated area, with reduced time and greater precision, capturing possible adversities in the plantation, such as pests, diseases, failures in planted areas, excess or shortage in irrigation in order to define areas of interest, survey the topography of the land, plan the drainage of rainwater, generate a crop health map. Some of these UAVs can be equipped with spray tanks, making it possible to apply fertilizers and pesticides in a precise and targeted manner to the affected areas.

In general, within precision agriculture, drones act as a tool for strategic planting management, optimizing processes, providing more information for decision-making. In this sense, the use of drones in agriculture contributes to better crop results, reduces production costs and also helps reduce environmental impacts, because with more accurate information, through sensing, mapping and data analysis technologies, drones allow for a more efficient use of resources, minimizing waste and reducing environmental pollution (Cavalcante et al., 2022).

However, there is specific Brazilian legislation for the use of drones in agriculture, whose objective is to ensure safety, privacy, and adequate control of airspace. The Ministry of Agriculture, Livestock and Supply establishes in Law No. 298 of 09/22/2021 rules for the operation of remotely piloted aircraft intended for the application of pesticides and the like, adjuvants, fertilizers, inoculants, correctives and seeds.

According to the legislation, the use of UAVs in Brazilian agriculture is regulated and inspected by the National Civil Aviation Agency (ANAC) and the Department of Airspace Control (DECEA). Therefore, these two bodies establish the rules, related to aspects such as registrations, licensing, flight zones, and technical requirements for the use of these vehicles in the national territory (BRASIL, 2021).

Among the requirements present in the legislation, the need for an authorization to operate drones in rural areas stands out, that is, the drone operator must be over 18 years old, be qualified, trained and registered to operate the aircraft, a document made by ANAC, in addition to the need to respect the security and privacy standards established by Brazilian legislation. At this point, it is also necessary that the vehicle itself be registered in the Integrated System of Agricultural Products and Establishments-SIPEAGRO, provided by ANAC and have RETA insurance (Civil Liability of the Explorer or Air Carrier) that aims to ensure safety in operations (BRASIL, 2021).

Another important requirement for the use of drones in agricultural areas, required by DECEA, is the presentation of an Operational Risk Worksheet. This document will serve to describe the main risks that drone operation can offer and the actions taken to reduce these risks. The legislation also establishes that drones can only map areas smaller than 15 km², and in the case of imported UAVs, approval by the National Telecommunications Agency (ANATEL) is required for the vehicle to operate legally in the national territory.

It is worth mentioning that although these machines have revolutionized several areas, including in the agribusiness sector, there are some situations that generate challenges for the use of these vehicles. One of the biggest challenges, for Alarcão Junior and Nuñez (2024), is the legislation, because according to the authors, it is still very

restrictive. Another situation, which can be considered challenging and disadvantageous is the high cost of implementing this technology, which becomes an impediment for many farmers.

Alarcão Junior and Nuñez (2024) point out that the combination of several technological and market factors makes UAVs so expensive. The authors claim that high-performance drones are equipped with the best technologies, such as high-resolution cameras, GPD systems, multiple sensors, navigation software, artificial intelligence, specific batteries, and these components have expensive prices.

Another factor that I built for the high cost of drones is maintenance, as they require specialized technical support, and qualified and trained subjects to operate them, which requires large investments from the producer (Alarcão Junior and Nuñez, 2024).

METHODOLOGY

This article has a qualitative approach through systematic bibliographic research. For Cardano (2017), qualitative research is characterized by the deepening of details, involves an interpretative approach to the world, so it is research with the objects of study in their natural scenarios, in the search for understanding the phenomena.

The study is a literature review. According to Sousa, Oliveira and Alves (2021), the literature review is based on the study of a theory already published, in which the researcher systematizes and selects all the material that contemplates the topic that will be addressed. Thus, during the bibliographic research, the researcher, in addition to reading, will reflect and describe the authors' thinking about the theme of their research.

As for the methodological procedures, in order to achieve the objective of this research, a systematic bibliographic review of scientific articles selected through a search in the databases of CAPEs Journals was carried out. During the searches, the following descriptors were used: Precision Agriculture, UAVs and drones. Works published in the last 10 years, in Portuguese and English that addressed the use of drones in precision agriculture, were selected.

RESULTS AND DISCUSSION

When searching the databases, applying the filters already mentioned, 12 articles published in CAPEs journals and 6 articles published in Scielo were found. However, after reading the titles, abstracts, keywords, and conclusion, it was noted that some of these articles did not fit the profile proposed for the research. Therefore, it was decided to apply criteria for the exclusion of works for the preparation of the bibliographic review, considering

aspects such as: lack of access to the full document, context of the research different from the topic addressed, duplicate article and bibliographic review article. In the end, 10 articles were selected, considering only those that were case studies on the theme of drones in precision agriculture

Thus, the present study will focus only on 10 articles presented in the table below that contemplate the proposed theme (Chart 1). The table presents the main data of the articles selected for discussion, organized by year of publication, and describing data such as the database from which it was taken, author, title of the article and journal where it was published.

Chart 1: Selected articles from CAPEs and Scielo journals.

AUTHOR(S)	TITLE	Database	Newspaper
Silva e Hachisuca (2019)	Study and development of a platform for Precision Agriculture using the SMART FARM concept using Unmanned Aerial Vehicles (UAVs)	CAPES	The Academic Sociely
Machado et al (2020)	Stress conditions in soybean areas based on measurements of soil-plant-atmosphere system and UAV images	SCIELO	Tropical Agricultural Research
Amaral et al (2020)	Applications of UAVs in Agriculture 4.0	SCIELO	Agronomic Science Journal
Souza et al (2021)	Impact of sprayer drone flight height on droplet spectrum in mountainous coffee plantation1	SCIELO	Brazilian Journal of Agricultural and Environmental Engineering
Galvencio and Naue (2021)	NDVI estimation with visible (RGB) images taken with drones	CAPES	Journal of Hyperspectral Remote Sensing
Arante et al (2021)	Spectral detection of nematodes in soybean at flowering growth stage using unmanned aerial vehicles	SCIELO	Rural Science
Tagliarini (2021)	Unmanned aerial vehicle images applied to obtain the normalized difference vegetation index	CAPES	Energy in agriculture
Castaldo (2023)	Revolutionizing agriculture from the skies: exploring the potential of spraying drones in precision farming	CAPES	Science and Technology Notebooks

Ferreira Neto, Rosa and Nuñez (2024)	Use of artificial intelligence in weed detection	CAPES	Brazilian Journal of Scienc
Hemalatha this Sageentha (2024)	Identifying pests in precision agriculture using low-cost image data acquisition	SCIELO	Brazilian Journal of Scienc

Source: Authors, 2024.

From the table it is possible to observe that the publications were carried out in the most diverse journals, with emphasis on the magazine "Brazilian Journal of Science" in which two articles were published. It is also observed that the year 2021 has the highest number of publications, according to the searches carried out.

Following a chronological sequence of publication, the first work found was written by Silva and Hachisuca (2019) who dealt in their research with a pilot project to create a platform for Android capable of controlling drones, using GPS, Google Maps and SDK, making the drone follow points capturing images at different angles and directions for post-processing of these images on the platform. According to the authors, the application will have the same applications as the software in the field, generating information for the producer to make a decision, but easier to access, as it will have a lower cost.

Amaral et al. (2020) address their studies on the main applications of drones in agriculture and in their results they were able to highlight five major opportunities in the use of drones in agricultural areas: topographic survey, physiological assessments, biophysical assessments, monitoring of biological targets, and spraying of phytosanitary products and application of bioinputs.

In this sense, Amaral et al. (2020) point out that the use of drones in agriculture has evolved a lot in recent years and according to the results of the research, the perspective is that this agricultural resource will replace low-performing human activities, such as monitoring sampling, in addition to contributing to the specific application of products, reducing time and costs. Thus, the flexibility, low cost, applicability and accuracy of data have made UAVs gain more and more space in agriculture.

Machado et al (2020) conducts research to assess the stress conditions in a soybean crop, using image processing techniques carried out by drones. The authors were able to verify that with the help of multispectral and hyperspectral cameras, drones can capture detailed images of crops, offering a more accurate and efficient approach to the crop.

In 2021, according to the searches, four studies were published addressing the use of drones in agriculture. Galvíncio and Naue (2021) conducted a survey to evaluate the NDVI (Normalized Difference Vegetation Index) estimate obtained with visible images

paying attention to radiometric calibrations. In general, the results of Galvíncio and Naue (2021) indicate that the images taken by drones allow for more accurate NDVI estimates, and this can be a very promising factor in agriculture.

Souza et al (2021) conducted a study on the impact of the flight height of a sprayer drone, that is, they analyzed the quality of the spraying in relation to the height of the flight and the position of the target in a coffee plantation. According to the authors, although both results are satisfactory compared to the other techniques, they were able to observe that while the flight height of the UAV influenced only the volumetric diameters parameters, the position of the target the spraying parameters studied. Finding that, depending on the type of crop, the unmanned aerial vehicle spraying system is more efficient for the lower part of the plant.

Tagliarini et al (2021) published a study addressing the elaboration of a thematic map through aerial photogrammetry and photointerpretation, with greater detail of the vegetation due to the very high spatial resolution achieved with the use of images collected by UAVs. The results presented images with high spatial resolution and demonstrated flexibility of use, having high potential for mapping landscape dynamics and spectral response of vegetation.

Also in 2021, Arante et al. (2021) published a study on the spectral detection of nematodes in soybeans, using unmanned aerial vehicles. The authors describe in their results that the spectral sensors contained in the drones were able to detect the nematodes present in soybean, although for one species the low-course spectral sensor was sufficient for visualization, while in another species of nematode multispectral sensors were needed.

One of the important uses of drones is in spraying techniques. In this scenario, Castaldo (2023) did a study addressing the use of spraying drones, their benefits, as well as the limitations that this drone activity offers. For information, the author used data from large and small properties that make use of this technology, comparing it with others that still use traditional resources.

In view of the results of Castaldo (2023), it can be seen that spraying with drones has a lower cost and spraying is faster than tractorized sprayers, in addition, it can reach hard-to-reach crops with better quality, and can also be enabled to fly at specific times. In this way, with combined with georeferencing systems and specific software, drones have become essential tools in spraying, with very satisfactory results compared to other methods, as it makes spraying occur at the precise place, time and dose, without waste and with less work time, optimizing crop management and meeting the principles of precision agriculture.

However, Castaldo (2023) points out that an important challenge for the use of spraying drones is their low capacity, high acquisition cost, and legal regulations that are necessary for their use in agricultural areas, and such factors mainly affect small-area farmers. Another point is about batteries, because with heavy batteries and short duration, spraying work cannot meet demands. However, the author states that despite the challenges, the use of spraying drones in precision agriculture is the way to revolutionize agriculture.

Ferreira Neto, Rosa, and Nuñez (2024) conducted a study addressing the use of artificial intelligence in weed detection, that is, using drones. The authors describe that from the mapping of the area, the UAV was able to identify and classify the weed vegetation within the crop. They are capable of mapping with high spatial resolution, bringing positive results for remote sensing.

The last work analyzed was by Hemalatha and Sageentha (2024), who surveyed the main aspects of drone aid in precision agriculture. Among the benefits, the authors highlighted the ability to analyze large amounts of data and in crop management, such as in the protection of crops against parasite infestations with pesticide applications, offering superior performance in relation to several other methods.

FINAL CONSIDERATIONS

From the results obtained in this study, the use of drones in agriculture highlight the crucial role of technologies in advancing the agricultural sector, promoting more efficient, sustainable, and accurate management. In this way, the integration of drones into precision agriculture practices offers numerous benefits, such as detailed monitoring of crops, which significantly assists in decision-making based on accurate data, and consequently reduces operating costs and improves productivity. In addition, the use of drones in agriculture has great potential in sustainability, promoting cleaner and more efficient agricultural practices by optimizing the use of resources such as water, fertilizers, and pesticides, minimizing environmental impact.

However, although precision agriculture is already a reality and the use of drones can bring great benefits to rural producers, there are limiting and challenging factors for the use of drones in precision agriculture. One of the main limitations is the issue of the current legislation, which is extremely restrictive, making it difficult for many farmers to access it. In this sense, it is important for farmers to stay up-to-date on current legislation, ensuring that the use of drones is safe, regulated, and efficient. Another challenging factor is the high cost

of acquiring these UAVs and the other supporting technologies necessary for their operation.

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