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Drone Technology in Precision Agriculture: Are There No Environmental Concerns?

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Abstract

The adoption of drones in precision agriculture is expanding at a rapid rate, and expected to rise even faster as improvements in the technology result in cheaper models. Studies on the economic impact of drone technology in precision agriculture present optimistic projections of increased global food production. But increased food production almost always comes with significant environmental concerns. This paper examines the environmental concerns of drone technology in precision agriculture. The methodology of this paper is theoretical analysis and extrapolation of current literature in order to reveal the gap which future research needs to fill. While proposing a new area that has not received the close attention of experts and researchers, the paper reveals future scenarios of environmental issues around the various methods of drone applications in agricultural practices.

Keywords: Drone technology, precision agriculture, agricultural practices, environmental impact, food security words

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1. Introduction

The world has become a better place than it was before technological innovation led to new and more efficient ways of doings things. In remarkable ways, technology has improved the way we now live, work, communicate, travel, and do virtually everything. For example, agriculture which naturally evolved as a crude means of human sustenance at the beginning of time, has been greatly transformed by technological advancement. Technological applications in agricultural practices have monumentally increased food production and so far prevented global food shortage in a world with surging population. The Food and Agricultural Organization predicts that by 2050 about 9.6 billion people on this planet would need to be fed (FAO, 2018). For that to be possible food production needs to increase by 70 per cent by that year, and it is being widely projected that the future of agriculture lies in smart farming (Schultheis, 2017). This implies that in the years ahead farmers will have to rely more on technology than they have been since the advent of mechanized farming following the industrial revolution of the 18th and 19th centuries.

Since the 20th century technology has driven agronomic advances in the development of improved seedlings, agro-chemicals and genetically modified food crops. These technological improvements in agricultural practices in both small and large farming systems have ensured that food production grapples with the high rate of global population growth. But for food production to adequately meet global population growth rate, it is now expected that the application of technology to agricultural practices must have to achieve more precision and production (Doering, 2014; Schultheis, 2017; FAO, 2018; Gartland and Gartland, 2018). Achieving precision in agricultural practices involves the application of farm inputs like seedlings and agro-chemicals according to the exact needs and requirements of farmland. It is a more effective and efficient farm management system that has become known as precision agriculture in that it combines communications and information technologies to correctly (at the right place and time) address temporal and spatial changes in the farm (Zhang and Kovacs, 2012; Mulla 2013; Hassan-Esfahani et al, 2014; Ipate et al, 2015; Jarman et al, 2016).

Existing literature is already replete with records of the agronomic and economic benefits of precision agriculture; it leads to optimisation of crop yield and higher output, enhancement in product and produce quality, and sustainable use of the dwindling variety of available agrochemicals (AUVSI, 2013; Hassan-Esfahani et al, 2014; Ipate et al, 2015; Jarman et al, 2016; FAO, 2018). The benefits of precision agriculture have become more identifiable with the adoption of drone technology in agricultural practices. Drone has been found to be most useful in precision agriculture and its adoption is expanding at a rapid rate, and expected to increase even faster as improvements in the technology result in cheaper and customized models. Findings from many studies on the economic impact of the use of drones in precision agriculture have optimistic projections of increased food production and higher standard of living for the world's population (AUVSI, 2013; Abdullahi et al, 2015; Jarman et al, 2016).

However, food production and consumption have been consistently ranked amongst the top three sectors having significant impacts on the environment (Page et al 2014; FAO, 2018). So far, no serious attention is given to the possible environmental consequences that may arise from drone technology in precision agriculture, especially in the years ahead when it is more widely adopted by farmers across the globe. The need to develop sustainable agricultural systems based on practices which do not only increase food production but are also less damaging to the environment (Llewellyn, 2018) calls for research scrutiny of drone technology in precision agriculture. Given the various methods of drones' adoption in agricultural practices, are there no environmental impact or concerns?

This paper examines this key question at a time when drone technology in precision agriculture is on the rise, and already proclaimed as the best means to ensure global food security in future (AUVSI, 2013; FAO, 2018). The methodology of this paper is theoretical analysis and extrapolation of current literature in order to reveal the gap which future research needs to fill. While this paper contributes to existing knowledge in the use of drones in agriculture, it however proposes an important area that has not received the close attention of experts and researchers.

2. Developments in Drone Technology

Drones are remotely-piloted airborne devices in varying sizes, shapes and weights. Also called unmanned aerial vehicles (UAVs), unmanned aircraft system (UAS) or remotely-piloted aircraft (RPA), drones are aircraft model without an on-board pilot but operated only by means of remotely controlled mechanism (Liu et al, 2016). Originally invented for military uses such as deploying missiles in enemy territories, gathering defence intelligence, and undertaking surveillance or reconnaissance missions, drones have since been developed for diverse civilian uses (Ajala, 2018). However, drones' architecture as an aircraft model and the nature of their uses necessitate that they are equipped with cameras for aerial photography or activities. Drones are therefore considered as potential threat to public safety and the privacy rights of citizens.

For example, there is a possibility that drones may crash into public places, deploy explosives to cause terror, or collide with manned commercial aircraft. Any of these scenarios may have disastrous consequences for public safety and national security. And drones' potential threat to the privacy rights of citizens may crystallize when private property is trespassed by drones' flights or when images of people are captured in their private property without their knowledge or consent. Thus, current regulatory frameworks for the use of drones in many countries are mainly as a result of public safety and privacy rights concerns about the proliferation of civilian drones (Wei, 2016). Regulations of drones operation due to public safety and privacy rights concerns have given rise to a debate on how the regulation of drones should proceed, the form and extent of regulation, and the impact of regulation on the technological development of drones (Peterson, 2006; Clarke and Moses, 2014; Clarke, 2016).

The central theme of the debate is how to adequately regulate civilian use of drone without stifling the development of drone technology and curtailing the immense benefits which the technology offers (Cho, 2013). Extant literature has mainly focused on this debate from different perspectives (Schlag, 2012; Olivito, 2013; Bennett, 2014; Smith, 2015; Clarke, 2016; Ajala, 2018). Agricultural drones' enthusiasts are opposed to strong regulations while supporting further development of drone architecture to be fully autonomous with artificial intelligence. It is noted that autonomy and intelligence capabilities would enhance drones versatility in precision agriculture for higher food production (AUVSI, 2013; Anthony, 2014). Current developments in drone technology are therefore significantly marked by opponents and supporters of its regulation, including those advocating for further improvements on the technology for maximum agricultural productivity.

3. Drones in Precision Agriculture

Drones in precision agriculture accounts for the largest share of civilian drones market. It is noted that the market for drone-powered solutions in agriculture is about $32.4 billion while the use of drones in precision agriculture is expected to increase at a compound annual growth rate of 42.25 per cent by 2020 (Schultheis, 2017; FAO, 2018). Precision agriculture involves the use of sensors to detect the conditions of soil and crops and applying with exactitude the requisite agro-chemicals. It is an innovative system of farm management different from the conventional system where large farmlands receive uniform treatment in the applications of seedlings, agro-chemicals and irrigation. In precision agriculture, large farm lands can be divided into management zones with each receiving customised management inputs based on varying soil types, topography, and management history (Mulla, 2013; Abdullahi et al, 2015; Jarman et al, 2016).

In the adoption of drone technology in precision agriculture, drones are deployed to carry out soil mapping, crop monitoring, thermal and multi-spectral imaging of crops canopy and farmland (Lin et al, 2015; Agüera-Vega et al, 2017). Underground internet of things which consists of a network of sensory and communications devices buried underground are linked to drones for faster data collection, and real-time analysis and decisions regarding the conditions of soil and crops (Faical, 2014; Vuran et al, 2018; Mogili and Deepak 2018). Underground wireless sensory network linked to drones are also used to monitor crop yield and biomass, and to detect plant nutrient and water stress, infestations of weeds, insects and plant diseases, including soil properties such as organic matter, moisture and pH content (Garcia-Sanchez et al, 2011; Mulla 2013; Lin et al, 2015).

Drone technology is thus expanding the type and quality of farm data that can be collected and this ensures the application of agronomic variables in the right place, at the right time and with precise control over the amount of material inputs or crop production (Ipate et al, 2015). Drones are proving to be the most effective precision agriculture tool that allows effective farm management at every stage and throughout crop life cycle. Though to unequal degrees, precision farming is been increasingly adopted in many countries across the world. Farmers in the US, Canada, and many European countries like the UK, Germany, France and Australia are noted to have adopted drone technology in agricultural practices mostly since the beginning of this 21st century. Other countries such as Japan, China, Argentina, Brazil, and India have also been identified with the use of drones in precision agriculture (Anderson and Gaston, 2013).

In particular, it is noted that drones carry out about 90 per cent of aerial crop dusting and spraying in Japan (AUVSI, 2013). In African countries like Nigeria, the awareness of drone in precision agriculture has been shown in the planning, design, and construction of rice irrigation systems and the establishment of irrigation scheduling (Le, 2016). The applicability of drone photogrammetry in modelling the topography of a farm land for the selection of a suitable site for the construction of an earth-fill dam has also been recently demonstrated in one Nigerian community (Ajayi et al, 2018). It is arguable that privacy rights and public safety regulations of civilian drones are currently impeding the pace of development and adoption of drone technology in agriculture in the developed countries. But full adoption of the technology in precision agriculture is a high possibility in the future.

For example, since 2013 in the US agriculture has been the main focus of the drone industry largest trade group, the Association of Unmanned Vehicles Systems International (AUVSI). The group pushes against regulations of civilian drones and predicts that an enabling legal regime would lead to agricultural drones accounting for 80 per cent of the commercial drones market between 2015 and 2025 (AUVSI, 2013). The US government is working out appropriate regulations that would allow drone technology in agriculture due to its potential economic impact (Geech, 2018). In the UK, there is consideration of how drone technology can become an integral precision farming tool exploitable by different users across the agricultural sector by 2020 (Jarman et al, 2016).

Also, drone technology in precision agriculture is gradually gaining traction in developing countries because of its increasing availability and lower prices. This is due to the rapid development of drone operational accessories like the miniaturized GPS sensor and high-resolution digital camera, including the efforts of drone hobbyists and enthusiasts who are supplying research and development at no cost (Freeman and Freeland, 2014). The relative low rate of adoption of the technology due to current restrictive regulations and limited awareness of its benefits, would certainly pave the way for full adoption in the years ahead. According to the Garter Hype Cycle, after the period of disillusionment following deregulation of civilian drones, there should be an uptake of drone in precision agriculture after expectations of its contributions and benefits are realized – the plateau of productivity at which stage there is comprehension of the technology's contributions and benefits (Freeman and Freeland, 2015; Jarman et al, 2016).

It is expected that when drone technology would revolutionize agriculture in the future, fully autonomous drones with artificial intelligence would carry out collection and analysis of farm data instantaneously and more efficiently. Drones would be capable of automatically identifying different crop varieties, categorising and mapping weeds, and swiftly assessing crop damage from pests or nutrient deficiency (Doering, 2014; Greenwood, 2016). Crops would be able to receive an individually customised agro-chemicals prescription that varies with soil type and topography in a way that ensures that crops are managed plant-by-plant (Mulla 2013). Currently, it is yet to be determined what impact drone methods of achieving precision agriculture may have on the environment. But from the literature, the use of drones in precision agriculture is directly on the soil and in the air. This includes drone systems integrated with underground sensory networks in soil and crop monitoring, and in applying agro-chemicals.

3.1 Drones with Underground Sensory Network in Soil Monitoring

It is important for farmers to determine the condition of soil before planting decision is made because not all soil types or locations are suitable for all crops. With drone technology, the determination is made based on soil map which can be used to measure soil suitability and variability. For instance, the measurement of soil electrical conductivity can provide indicators of soil properties like soil moisture, salinity or clay content, soil pore size and distribution, including soil temperature (Ali et al, 2015). While soil moisture content is a good way to identify the water and energy exchange between the soil surface and the atmosphere, the salinity content of soil can clearly limit the productivity of irrigated land (Zhang and Kovacs, 2012; Dong and Vuran, 2013b). Soil electrical conductivity measurements used to map spatial patterns in soil salinity, clay and moisture content are applied to define farm management zones, and precision agriculture practices such as variable rate seeding and nitrogen application are determined based on zoning (Mulla, 2013; Burud et al, 2017).

After planting decision is made according to the soil analysis, drone-planting systems have been developed which shoot pods with seeds and plant nutrients into the soil, providing the plant all the nutrients necessary to sustain its healthy growth (Laskar and Mukherjee, 2016). Interfaced with underground sensory networks, drone technology also provides real-time near infrared measurement for mapping soil texture and organic carbon, including real-time measurement of soil PH reflectance spectra using near infrared reflectance spectroscopy (Bricklemyer and Brown, 2010; Pederi and Cheporniuk, 2015). Monitoring and measuring soil properties, including soil topography or elevation, and collecting data for analysis is achieved through drones' remote sensing applications based on the interaction of electromagnetic radiation with soil (Pignatti et al, 2014; Rossel and Bouma, 2016).

Remote sensing of soil moisture, using a drone with high-resolution multispectral imagery provide information on soil water holding capacity and suitable irrigation systems (Diaz-Varela et al, 2014). It has thus made soil analysis and decision making as to planting easier, more accurate and efficient. Drones' remote sensing of soil nutrients is also applied for predicting crop health and production quality which depend on the soil condition (Bricklemyer and Brown, 2010; Colomina and Molina, 2014; Hassan-Esfahani et al, 2015; Baenaa et al, 2017). In addition, irrigation scheduling is predicted with drones' remote monitoring of the soil structure and moisture to determine the orientation of rows and the use of strips to reduce erosion (Hassan-Esfahani et al, 2014). In one example in Nigeria, drone imagery in the planning of a rice farm was used to make decisions on the layout of both rice paddies and the irrigation systems (Greenwood, 2016).

With drone technology, there is an increasing automation of agricultural practices more than it has ever been in the history of agriculture. Automation of soil monitoring, land topography, and measurement of soil properties is progressing rapidly with the use of drones equipped with advanced land imager and airborne imaging spectrometer (Lucieer,et al, 2014; Diaz-Varela et al, 2014; Brignoli et al, 2018). Agricultural drones use optical infrared techniques or electromagnetic sensors to capture high resolution images of soil properties and land topographic layouts for analysis and inputs decisions (Al-Arab et al, 2013; Ajayi et al, 2017a). A network of sensory devices buried underground generates electromagnetic frequencies and engages the drones in wireless communications that produce data which is analysed, and used to make better farming decisions that lead to higher production (Costa et al, 2012; Chen et al, 2015; Salam et al, 2016; Vuran et al, 2018).

3.2 Crop Monitoring and Application of Agro-chemicals

Drone technology has transformed the methods of applying agro-chemicals and monitoring crop growth throughout life cycle. During crop growth, drones are used for scouting hectares of fields in single flight, and with thermal and multi spectral cameras record reflectance of vegetation canopy (Mogili and Deepak, 2018). The reflectance of electromagnetic energy by the crop canopy at different wavelengths is predictive of important physiological traits such as nitrogen content, photosynthetically active biomass, leaf chlorophyll and plant water status (Liu et al, 2015). Canopy reflectance has thus replaced traditional methods and is capable of screening large numbers of field plots in a fast and efficient manner. Drones equipped with sensors easily collect multispectral Neutral Density Vegetation Index (NDVI) and infrared images which provide sufficient view of crop changes that are otherwise invisible to the human eye during manual or ground level crop scouting (DeJonge et al, 2015; Tang et al, 2018).

The aerial data obtained are used to speed up the painstaking process of conducting crop inventories and yield estimates because as the crop is growing, the data allows the calculation of the vegetation index, which describes the relative density and health of the crop, and show the heat signature, the amount of energy or heat the crop emits (Brignoli et al, 2018). Spectral measurements have traditionally been obtained using hand-held or tractor-mounted sensors but with drone technology, multispectral imaging now offers the possibility to combine spectral radiation with spatial information and thus perform a simultaneous phenotyping of both the physical structure of soil and physiological conditions of crops (Mahlein Steineret al, 2010; Kukal and Irmak, 2017).

Hyperspectral remote sensing is also used to record weed densities, crop height, and the detection of pest and disease infections. Hyperspectral sensors with drone technology make it easier and faster to understand carbon uptake in a crop canopy, assess crop health by early identification of bacterial or fungal infections on crops through scanning cropland using both visible and near-infrared light (Bendig et al, 2012; Mulla, 2013; Ipate et al, 2015). The sensors can identify which plants reflect different amounts of green light and near infrared light and this information can produce multispectral images that track changes in plants and indicate their health status. Early detection of bacteria or fungal infection means a swift response by applying appropriate agro-chemicals more precisely. Drone aerial hyperspectral imagery has thus revolutionised the ability of farmers to quickly distinguish multiple soil and crop characteristics, including nutrients, water, pests, diseases, weeds, biomass and canopy structure (Mulla, 2013; Lin et al, 2018).

What is most relevant and worthy of note about drones in precision agriculture is that the methods of conventional agricultural practices are being taken over by more advanced techniques. This fits into the concept of technological development which means improvement on the old system or better way of doing usual things. However, in spite of the improvements so far introduced by drones in precision agriculture what has not changed is the natural environment and its constituents such as soil and air or the atmosphere which drone-driven agricultural practices engage or manipulate. While the different techniques through which drone technology utilizes the air or the atmosphere and manipulates the soil is resulting in higher production at reduced costs, what is yet to be determined is the trade-off those techniques may have with the environment. The environmental cost of increased farm output at minimal effort which drones in precision agriculture provide is yet to be determined, let alone quantified.

4. Environmental Concerns in Precision Agriculture with Drone Technology

The impact of drone technology in precision agriculture is easily identifiable with the transformations it has caused in agricultural practices. The positive impact is that it generates greater productivity at reduced costs. For example, soil and crop monitoring was initially carried out mostly with satellites and manned aircraft while spraying of agro-chemicals started with aircraft. Besides the enormous costs of using these older technologies, empirical studies show that aerial images of the conditions of soil, crops and farmlands captured by drones are of higher spatial resolution and accuracy than those by satellites and manned aircraft (Lucieer, et al, 2014; Stark et al, 2015; Senthilnathet al, 2017). Unlike drones, variable rate of spraying agro-chemicals can never be achieved with precision and efficiency by the use of manned aircraft (Spoorthiet al, 2017; Tziavouet al, 2018).

Precision and efficiency in the use of farm inputs which drone technology provides mean more effective farm management, and this inevitably leads to higher output.at relatively lower cost. The common view in existing literature is that drone technology is revolutionizing agriculture and presents a veritable means to achieve global food security in the future (AUVSI, 2013; (Doering, 2014; Schultheis, 2017; FAO, 2018; Gartland and Gartland, 2018). Some have opined that increasing precision in the application of farm inputs like agro-chemicals at a correctly variable amount and time results to a reduction of the environmental effects of the chemicals; and that drone technology in precision agriculture is contributing to a more sustainable way of farming as agriculture production is achieved with minimal environmental impact (Zhang and Kovacs, 2012; Mulla 2013; Hassan-Esfahani et al, 2014; Ipate et al, 2015; Jarman et al, 2016). But these claims are only apparent and yet to be empirically validated.

As a historical driver of societal change, technology has manifested unintended environmental consequences some of which the world is currently struggling to ameliorate. An example is mechanisation of all forms of production with intense use of fossil fuel as a fallout of the industrial revolution, the environmental consequence being the current greenhouse effect and climate change (Llewellyn 2018). In recent times, there has been a growing awareness that rapid increase in agricultural production to meet the demand of rising global population will be a major driver of unsustainable global environmental change. This has led to greater recognition that decision making in technology selection needs to change from a predominantly economic standpoint to environmentally sound technologies (Page et al, 2014).

An environmentally sound technology is one that is capable of reducing environmental damage through processes and materials that generate fewer potentially damaging substances, recover such substances from emissions prior to discharge, or utilize and recycle production residues (OECD, 2003). Drone technology in precision agriculture is yet to be determined as environmentally sound. While no significant environmental concerns have been raised about drones in precision agriculture, possible existence of its environmental impact cannot be dismissed in the absence of empirical evidence. More so, recent studies related to determining the environmental impact of the use of drones in the package delivery industry do not find drone technology as absolutely environmentally harmless.

Figliozzi (2017) presented a lifecycle modeling and assessment of drones' potential effectiveness to reduce Carbon dioxide emissions (CO2e) lifecycle, compared to conventional diesel vans, electric trucks, electric vans, and tricycles. The findings concluded that drone deliveries are not more CO2e efficient than tricycle or electric van delivery services in certain situations like where a few customers can be grouped in a route. The lifecycle analysis shows that drone vehicle phase emissions are significant and that when lifecycle emissions are considered and taken into account, an electric tricycle is likely to be more CO2e efficient than the drone. Such that, in dense urban areas where tricycle deliveries can be economically feasible, tricycles are likely to outperform drones in terms of both energy consumption and lifecycle of CO2e.

A similar study by Park et al (2018) evaluated and compared the environmental impact of existing electric motorcycle delivery system and a newly introduced drone technology to deliver food using the lifecycle assessment. The study finds that the global warming potential per 1 km delivery by drone was one-sixth that of motorcycle delivery, and the particulates produced by drone delivery were half that of motorcycle delivery. However, the study reveals that increasing the use of environmentally friendly electricity systems, such as solar and wind power, would further enhance the environmental effects of a drone delivery system. This implies that current civilian drones that are mostly powered by batteries, or gasoline like the Japanese Yamaha RMAX crop sprayers, are not environmentally sound in terms of energy consumption and CO2e.

The findings of another recent study by Goodchild and Toy (2018) suggest that within the context of environmental impact, not only drones but a blended system involving drones and delivery trucks would perform best or generate the least emissions in the business of package delivery. The study estimated CO2e and vehicle-miles travelled levels of delivery trucks and drones. The findings are that under conditions such as proximity of service zones to depot and limited numbers of stops, drones are likely to provide a CO2e benefit, but delivery trucks almost firmly have CO2e advantage over drones where service zones are both far away and have high amounts of recipients (Goodchild and Toy, 2018). While these studies only analyse the energy use and CO2e of drones in the package delivery industry and not in precision agriculture, the findings provide significant insights into potential environmental impact of drones in precision agriculture.

In particular, the studies do not explore the net environmental impact of emissions such as nitrous oxides and other particulates, nor do they examine what potential effects drone-integrated sensory network with batteries buried underground, hyperspectral electromagnetic imaging of soil and crops, and precision spraying of agro-chemicals would have on the environment. Thus, there is need for a comprehensive study of the potential impact of drone technology in precision agriculture and specific analysis of what effect each method of drone agricultural practices may have on the environment. Even a lifecycle assessment of drone technology in precision agriculture may provide a vista of what potential environmental concerns may lurk around the technology. Lifecycle assessment provides a comprehensive perspective of the environmental impact of a technology along its life cycles or stages such as extraction of raw materials from the earth, materials processing, manufacturing, distribution, product use and disposal or recycling at the end (Figliozzi, 2017).

As drone technology is undergoing development, now is the time to begin to understand its potential environmental impact so that remedial steps are taken along its developmental trajectory. Now is the time to be certain that drone technology in precision agriculture will not have the deleterious environmental impact that has followed massive intensification of agricultural production since the last two centuries. It cannot be taken for granted that drone technology in precision agriculture is inherently environmentally friendly. As Fisher-Vanden and Ho (2010) have cautioned, better technology does not necessarily imply a cleaner environment. The discovery or revelation of possible harmful environmental impact of drone technology in precision agriculture would not imply that the technology should be banned or abandoned. It would only open new areas of it development to ensure environmental protection and sustainable agricultural production. Thus, empirical environmental concerns about drones in precision agriculture would lead to further technological developments aimed at remedying or preventing their future occurrence. As Foray and Grubler (1996) have long posited, relevant and viable solutions to environmental problems call for more, and better mastery of, technology not less.

5. Conclusion

The environmental impact of technologies that are used within our environment is seldom recognised or considered until its harmful or destructive manifestations. Since its historical emergence, technology has been too good to be devoid of any down side. Technological advancements, as the world has witnessed, have come with their peculiar environmental effects or concerns. In particular, increases in agricultural production brought about by modern farming techniques such as mechanisation have been associated with significant environmental problems. The environmental impact of drone technology in precision agriculture may be unique to the technology in a way that has not been known. The principles of sustainable development (which encompass sustainable agricultural production) underscore the need to empirically determine any potential environmental impact of drones in precision agriculture. Sustainable development implies that environmental protection is considered in all processes or practices that directly bear on the environment. Sustainable agricultural production thus requires empirical knowledge of the environmental impact of precision agriculture with drone technology. Environmental impact assessment research is thus necessary to the development and adoption of drone technology in precision agriculture.

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