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Drones in Insect Pest Management: Transforming Agriculture with Precision Technology

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Abstract

Precision agriculture depends heavily on crop health monitoring, and drones play an essential role in detecting on-site issues and enabling timely corrective actions. In India, where labour and technical expertise are often limited, drones present a valuable solution for advancing smart farming practices. Insect pests remain a significant challenge, reducing food grain production worldwide. In India, small and marginal farmlands complicate pest management, as spraying one field can often drive pests to neighbouring areas, making consistent control difficult. Although drones offer high-resolution capabilities for precise, site-specific farm management, their broader adoption faces regulatory restrictions. These guidelines, set globally, limit the potential for drones in agriculture. Addressing these regulatory hurdles could unlock the full benefits of drones, enhancing productivity and pest management. By facilitating drone usage, India could make significant strides in agricultural efficiency, empowering farmers to better combat pests and boost crop yields across diverse landscapes.

1. Introduction

In the present era, there are too many developments in precision agriculture for increasing the crop productivity. Especially, in the developing countries like India, over 70% of the rural people depend upon the agriculture fields. The agriculture fields face dramatic losses insect pests and diseases, which reduces the productivity of the crops. Pesticides and fertilizers are used to kill the insects and pests in order to enhance the crop quality. The WHO (World Health Organization) estimated as one million cases of ill effects, when spraying the pesticides in the crop filed manually. The Unmanned aerial vehicle (UAV) – aircrafts are used to spray the pesticides to avoid the health problems of humans when they spray manually. UAVs can be used easily, where the equipment and labours difficulty to operate (Zhang and Kovacs, 2012).

Drone technology is a phenomenal innovation with potential

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to transform the way the routine manual activities are carried out in agriculture. Agricultural industries globally are increasingly using drone technology to modernize farming. Drones are the remotely piloted aircraft systems (RPAS), having a propulsion system, a programmable controller with or without the satellite navigation system, automated flight planning features and capable of carrying payload such as cameras, spraying systems, etc. for accomplishing a given task. Several other acronyms, namely UAV/UAVs (Unmanned Aerial Vehicle Systems^{-1}), UAS (Unmanned Aircraft Systems) are interchangeably used; however, RPAS is the most formal and international way of addressing such systems. The drone used for agricultural activities is known as agriculture drone. Drones are designed to carry the sensors that can provide real-time information about the crop status or livestock movement, so that decision on cultural operations and management is made efficiently and precisely. The drone can be either remotely controlled over wireless communication or can be programmed to travel the predefined path using complex navigation algorithms running on onboard controllers (Hardin and Jensen, 2011). It can be retrofitted with different configuration of payloads of sensors with digital imaging capabilities such as multi spectral, high-resolution camera systems and actuators, for field survey, crop scouting, spraying and spreading applications and surveillance in livestock and fisheries. Using the data captured through cameras mounted on drone and data analytics, farmers can precisely calculate their land sizes, classify crop types and varieties, develop soil maps along with pest management and properly plan the harvesting of their crops. These drones can be fully automated to help further improve the scale of operation and productivity. Drones have found several applications in agriculture, however is limited by the country policies on its use context (Pathak et al., 2020).

2. Applications of Drones in Agriculture

2.1. Soil and field analysis

Drones can be used to mount sensors which are able to analyses the soil conditions, terrain conditions, moisture content, nutrients content and fertility levels of the soil which can be further used for planning the pattern of sowing of different crops, irrigation scheduling as well as for managing fertilizers application considering spatial variability of the crop growth and field conditions.

2.2. Planting crops and trees

Drones are used for planting crops which can save labour cost and reduce human drudgery. As there would be no use of tractors for sowing crops in the field, drones can save fuels, reduce the emission of harmful gases formed during fuel exhaustion while operating tractors in the field, and can avoid the compaction of subsoil as well as formation of plough pan which generally forms due to repetitive movement of tractors on soil surface.

2.3. Crop monitoring

Drones can be used for monitoring the conditions of crops throughout the crop season so that the need-based and timely action can be taken. The quick and appropriate action can prevent yield loss. This technology will eliminate the need to visually inspecting the crops by the farmers. They can monitor the horticultural crops or other crops present in remote areas like mountainous regions. They can also monitor the tall crops and trees efficiently, which are otherwise challenging to scout physically by farmers.

2.4. Weed identification

Drones can be used to identify the weeds present in the field. These weeds could be timely rooted out from the field so that they do not compete for resources with the main crop.

2.5. Geofencing or protecting the field from animal damage

The thermal cameras mounted over drones can detect animals or human beings during the night. So, it can be used to protect fields from the damage caused by animals, which are otherwise difficult to detect in the large fields during night time. So, it will work more efficiently than human guards.

2.6. Crop insurance

Drones can be used for precisely estimating and monitoring of the crop failure. So, it can be helpful for the farmers as well as for insurance companies in providing insurance claims based on the degree of damage. This technology has great potential in accurate and effective implementation of crop insurance scheme, namely Pradhan Mantri Fasal Bima Yojana in India without any bias.

2.7. Livestock management

Drones can be used to manage the large herd of livestock. The sensors having high-resolution infrared cameras present over drone can detect the diseased animal swiftly by their heat signatures. The detected diseased animal can then be separated from their fellow animals, and the early treatment can be provided. So, the drone could be used for precision dairy farming.

2.8. Irrigation scheduling of crops

Drones having sensors for optical, multispectral, and thermal imaging which can pinpoint the heat and water stress in the crops at a specific location. It can be used to apply irrigation to the crops based on their requirement. This will prevent the wastage of water and will ensure the efficient utilization of irrigation water.

2.9. Crop spraying

Drones can be used to spray chemicals like fertilizers, pesticides, etc. based on the spatial variability of the crops and field. The amount of chemicals to be sprayed can be adjusted depending upon the crop conditions, or the degree of severity of the insect-pest attack. In this way, drones pave the pathway to precision agriculture. This ultimately increases the efficiency of the chemicals applied, thereby reducing their adverse impacts on the environment by decreasing the soil and water pollution. Thus, it can lead towards sustainable agriculture. Drones spray chemicals at a faster rate as compared to other methods. It can also result in the saving of the amount of chemicals applied, which can reduce input cost. There is also a problem of imbalance of tractor operated machinery while spraying chemicals over tall crops which may sometimes result in accidents. So, the spraying of chemicals over tall crops can be done easily by drones without any damage (Rani et al., 2019).

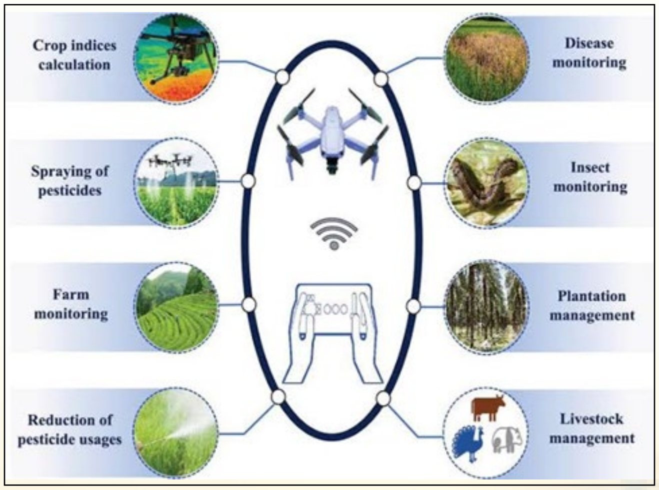

Figure 1: Application drones in Agriculture

3. Sensing Drones to Monitor Crop Health

Traditional field scouting for pest infestations is often expensive and time-consuming. It may be practically challenging, such as when a large acreage is involved, when the arthropod pests are too small to see with the naked eye, or when they reside in the soil or in tall trees. In some cropping systems, effective scouting is hampered by lack of reliable pest sampling techniques. Hence, one of the main drivers for the implementation of drone-based remote sensing technologies into agriculture is the potential time saved by automatizing crop monitoring, making the technology cost-effective for growers.

Compared to conventional platforms for remote sensing, such as ground-based, aerial and orbital sensing, sensing drones present several advantages that make them attractive for use in precision agriculture. Sensing drones potentially allow for coverage of larger areas than ground-based, handheld devices. They can fly at lower altitudes than manned aircraft and orbital systems, increasing images' spatial resolution and reducing the number of mixed pixels. Also, they cost less to obtain and deploy than manned aircraft and satellites and do not have long revisiting times like satellites, allowing for higher monitoring frequencies (Fernando et al., 2020).

4. Drones in Insect Pest Management

4.1. Sensing drones

• Drones used for detection of pest.

• Sensing drones could reduce the time required to scout for pests.

4.2. Actuation drones

• Drones used for precision distribution of solutions are referred to as actuation drones

• Actuation drones could reduce the area of pesticide applications.

• Reduce the costs of dispensing natural enemies (Xiongkui et al., 2017)

5. Drones for Precision Application of Pesticides

Sensing drones helps detect pest hotspots; actuation drones could help control the pests at these hotspots. Pest hotspots could potentially be managed through variable rate application of pesticides. Aircrafts have been used for decades for pesticide sprays, but products are deposited over large areas, and a large amount is lost to drift. This is a concern for neighbouring terrestrial and aquatic ecosystems, as well as for human health. Major factors determining spray drift are droplet size, weather conditions and application method. Therefore, improved methods of pesticide application are highly needed and there is potential for the use of drones in precision application of insecticides and miticides. Some of the aspects that give drones a competitive edge over manned crop dusters is their relative ease of deployment, reduction in operator exposure to pesticides, and potential reduction of spray drift (Fernando et al., 2020).

Figure 2: Drone with predatory mite dispenser

6. Drones for Precision Releases of Natural Enemies

Biological control is a potential sustainable alternative to pesticide use. It is the use of a population of one organism to decrease the population of another, unwanted, organism. Biological control organisms include, parasitoids, predators, entomopathogenic nematodes, fungi, bacteria, and viruses. A large variety is commercially available. Drones may be a particularly useful tool for augmentative biological control, which relies on the large-scale release of natural enemies for immediate control of pests. They could distribute the natural enemies in the exact locations where they are needed, which may increase biocontrol agent efficacy and reduce distribution costs.

Figure 3: UAV-based early pest detection

Natural enemies, such as insect-killing fungi and nematodes, can be applied with conventional spray application equipment. Therefore, these biocontrol agents could potentially be applied by drones as described above for pesticides. Release of natural enemies by aircraft was proposed in the 1980, but small drones would offer myriad possibilities. Coverage of larger areas compared to manual distribution, reducing application costs per acre, potentially increases the use of natural enemies in favour of pesticide sprays. Development of drone-mounted dispensers has mainly focused on two types of natural enemies: predatory mites such as the above-mentioned *Phytoseiulus persimilis*, and parasitoid wasps such as the egg-parasitoid Trichogramma spp. Other types of natural enemies can be drone-applied as well, such as green lacewing and minute pirate bug to control aphids and thrips, and mealybug destroyer to control mealybugs (Fernando et al., 2020).

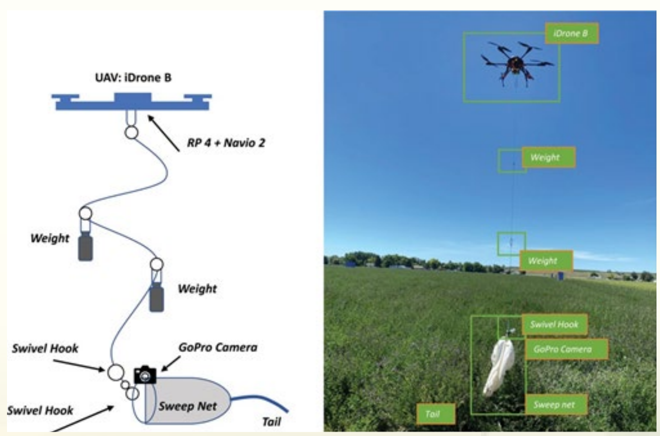

Figure 4: Drone for insect sampling

7. Novel Uses for Drones in Precision Pest Management

7.1. Pest outbreak prevention

Sensing and actuation drones could potentially contribute to the prevention of pest outbreaks. Plants exposed to abiotic stressors, such as drought and nutrient deficiencies, are often more susceptible to biotic stressors. This holds true for a large variety of arthropod pests, such as spider mites, aphids, and lepidopteran larvae. Due to this well-established association between abiotic stressors and risk of arthropod pest outbreaks, it may be argued that precision application of abiotic stress relief, such as application of water and fertilizer, represents a meaningful approach to reducing the risk of outbreaks by some arthropod pests. Indeed, pest management focus could shift from being based mainly on responsive insecticide applications to a more preventative approach in which maintaining crop health is the main focus Use of sensing and actuation drones could contribute to this shift, by assessing plant stress status, and preventative applications of water and fertilizers. To the best of our knowledge, drones have thus far not been deployed for precision irrigation purposes, and although drones are on the market that advertise the capacity to apply liquid or granular fertilizers, there is no peer-reviewed literature on their use. Many current spray tractors contain options for variable rate applications of nutrients, for an adequate response to deficiencies detected with remote sensing. However, there would be myriad opportunities for use of drones in this respect, due to their manoeuvrability and capacity to treat small areas (Fernando et al., 2020).

7.2. Reducing pest populations: sterile insect technique and mating disruption

A potential new area for use of drones in pest management is the release of sterile insects. Codling moth, pink bollworm in cotton, Mexican fruit fly citrus, with drone-released sterile insects proved effective for control of these pests. The sterile insect technique (SIT) produces sterile or partially sterile insects through irradiation. After mating with wild insects, there is either no offspring, or the resulting offspring is sterile, resulting in reduced pest populations. SIT is environmentally friendly, species-specific and compatible with other management methods such as biological control, making it an important IPM tool. Drone release of the sterile insects may be cheaper and faster than ground release, which occurs for instance by means of all-terrain vehicles (ATVs), or release by manned aircraft. For sterile codling moth, drone-dispersal may also improve moth performance. Drones release the moths above the canopy whereas ATVs release them on the orchard floor. Codling moth prefer to mate in the upper one-third of the canopy, thus drone release may facilitate the moths reaching their preferred habitat, while minimizing biotic and abiotic mortality factors. Irradiated moths must be kept chilled during transportation prior to orchard dispersal to prevent damage and scale loss. An optimized delivery system from the rearing facility to the orchard may increase the sterile moths' effectiveness in mating with wild moths. Therefore, drone releases may make SIT more widely available.

Drones could also be deployed to place mating disruptors such as SPLAT (specialized pheromone & lure application technology) in commercial fields. SPLAT is an inert matrix which can be infused with pheromones and/or pesticides and is applied as dollops. Mating disruption relies on the release of pheromones, which interferes with mate, while attract-and-kill involves an attractant and a killing agent. A combination of these methods effectively controls various pests in a number of cropping systems (Fernando et al., 2020).

7.3. Pest population monitoring

Drones also used to track populations of mobile insects that can be equipped with transponders, such as locusts. A recent paper by Stumph et al. (2019) described the use of drones equipped with a UV light source and a video camera to detect fluorescent-marked insects. Brown marmorated stink bugs (*Halyomorpha halys* Stal), 13–16 mm long, were coated in red fluorescent powder, and placed in a grass field. Drone data were obtained at night, and specific software was developed to visualize individual insects. This system provides a relatively fast alternative for manual, time-consuming, mark-release-recapture studies. Although insects still need to be coated initially, the method eliminates the need to physically recapture the insects. Also, it removes the need for destructive sampling, so that insects could potentially be sampled over a longer time period. Thus, use of this novel, drone-based system could improve efficiency and cost-effectiveness of mark-release-recapture studies of insect migration.

Drones could be used to collect pest specimens for monitoring or to survey for pests, such as Asian long horned beetles, in tall trees, assisting tree climbers. A recent review has even suggested the use of drones for collection of plant volatiles (Gonzalez et al., 2018). Indeed, plant volatiles induced in response to herbivory could indicate the presence of specific pests and drone-based volatile collections have been deployed for air quality measurements. Development of novel sensors and technology will undoubtedly open the door to various other uses of drones in agricultural pest management.

8. Conclusion

Drones equipped with remote sensing sensors monitor crop health, map performance variability, and detect pest outbreaks in precision agriculture and IPM. Early detection through sensing drones' aids in preventing large pest outbreaks. When outbreaks occur, actuation drones can swiftly deliver solutions like automated pesticide applications or biological control organisms to identified hotspots. This multi-disciplinary approach, integrating sensing and actuation drones, holds immense commercial potential through collaborative engineering, ecological, and agronomic research.

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