STANDARD OPERATING PROTOCOLS (SOPs) FOR DRONE BASED PESTICIDE APPLICATION IN RICE

Striving for a Greener Tomorrow

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Sri. M. RAGHUNANDAN RAO
I.A.S
Vice Chancellor

Foreword

Use of drones (UAVs) in modern agriculture is an emerging technology in India. The global agricultural drones market is expected to witness 18.5% compound annual growth rate (CAGR) during the forecast period of 2018 – 2026. UAVs offer huge potential for addressing several major challenges in global agriculture, particularly in crop health monitoring, agrochemical spraying and precision agriculture. The WHO (World Health Organization) estimated that one million applicators have been subjected to ill effects of manual pesticide spraying in crop fields. Drones can become one of the alternative strategy to reduce operational exposure in terms of maneuverability.

Development of best management practices (BMPs) to enable drone deployment for agrochemical spraying can aid in quicker and efficient pest management. Lack of crop specific standard operating protocols (SOP's) for drone spraying duly supported by scientific backup has been identified by PJTSAU as one of the major constraint either to develop regulatory framework or to guide farmers on drone technology.

Leading from the front, PJTSAU has initiated innovative project in this direction during 2020-21 and developed crop specific SOP's targeting seven crops *viz.,* rice, cotton, redgram, groundnut, soybean, sesame and safflower, where the pesticide consumption is reportedly quite significant in the State.

This book showcases the efforts of PJTSAU in taking forward drone technology for pesticide spraying in rice to diffuse any misconceptions on the subject. I compliment and congratulate the efforts of scientific team for bringing out this book to benefit all the stakeholders in the country.

Hyderabad
10th Dec, 2022

(M. RAGHUNANDAN RAO)

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Dr. V. Praveen Rao
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Message

India is one of the major players in agriculture sector globally and about 58% of Indian population thrives on this sector. Agriculture and allied exports stood at US $ 50.21 billion with gross value added (GVA) at 18.8% in FY 2021-22. The thrust has been on optimizing resource use be it natural resources, inputs or labour through policy support for farm mechanization, precision agriculture, agri marketing and value addition. Agriculture 4.0 including IOT, big data analytics, drones, sensors *etc.,* is being highlighted as the next revolution that will greatly influence the agri food sector. Farmers adopting modern agricultural practices are inclined to use drones for various farm operations, because of their precision and efficiency. They are quite useful in crop health monitoring, agrochemical spraying, yield forecasting and promote smart agriculture. In scenarios where farmers rely heavily on pesticide spraying for management of various crop pests, drones can be deployed not only to enhance spray efficiency, but also to reduce operational hazards to applicators.

However, lack of crop specific standard operating protocols (SOP's) for drone spraying has been the major stumbling block in placing this technology on the right footing. PJTSAU has taken a lead to demystify this technology by developing evidence based SOPs to deploy drones for pesticide spraying in several crops like rice, cotton, redgram, groundnut, soybean, sesame and safflower which occupy more than 95% of cropped area in Telangana state.

It is our sincere hope, that this work will inspire other scientists to delve into several important applications of drone technology such as ultra high dimension pest scouting, site specific pesticide spraying etc., to reduce the quantum of pesticide use in the days to come.

This book throws light on the research initiatives of PJTSAU on use of drone technology for pesticide spraying in rice. I register my sincere appreciation for the efforts of the scientific team in not only executing the research but also sharing the outputs through this book.

Hyderabad
10th Dec, 2022

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Message

The share of Indian Agriculture sector in the country's GDP has been hovering around 18% and the sector still provides livelihood to more than 50% of the population. There has been a radical transformation in the agriculture sector with adoption of improved varieties and technology, efficient inputs and greater adoption of mechanization. Agriculture is in the cusp of another revolution – centered around data and connectivity with increasing utilization of Artificial intelligence, analytics and connected sensors. This is expected to further improve the productivity and efficiency in use of water and other inputs besides building sustainability and resilience.

Unmanned Arial Vehicles (Drones) are now being promoted extensively in agriculture. Drones can be deployed extensively in agriculture for crop health monitoring, soil health assessment and improving resource use efficiency. Government of India is promoting the use of 'Kisan Drones' for crop assessment, digitization of land records, spraying of pesticides and nutrients extensively through implementation of targeted schemes.

Improving the adoption of drones for spraying of pesticides and nutrients calls for developing crop specific best management practices (BMPs) and Standard Operating Protocols. In this regard, I am happy to learn that Professor Jayashankar Telangana State Agricultural University (PJTSAU) has initiated the efforts of developing SOP's targeting seven major crops in Telangana state *viz.,* rice, cotton, redgram, groundnut, soybean, sesame and safflower.

NABARD being an apex bank for Agriculture and rural development, it has been implementing various projects through various funds. One such fund is Farm Sector Promotion Fund through which NABARD is providing grant assistance to support farm innovations, technology transfer and capacity building of farming community in realm of agriculture and allied activities. NABARD has also partnered with PJTSAU in its initiative in developing of Package of Practices (POPs) for spraying of herbicides, foliar nutrients and pesticides in direct seeded rice using drone technology. I hope the present book on drone technology in rice will be helpful and handy to not only scientists but also farmers in utilizing drones effectively, efficiently and with utmost safety.

Hyderabad
10th Dec, 2022

SUSEELA CHINTALA

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Ph.D
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Preface

One of the crucial operations in plant protection of different principal crops has been the use of pesticides. Recently, remote-controlled unmanned aerial vehicles (drones) have gained popularity as a new platform to monitor and manage agricultural pests in various crops.

In India, drones have promising potential for monitoring and management of insect pests and diseases due to scarcity of labour, especially having spraying skills and huge area under rice (41.2 lakh hectares) in Telangana State to be covered within a limited time. It has the advantage of precision delivery of chemicals to right place at right time without exposing the spray operator to harmful chemicals apart from saving time and labour.

Despite the huge potential, use of drones in agricultural fields has been limited to a few countries including the United States, China, Japan and very few attempts have been made in India in general and Telangana state in particular. Of late, few drone operators are spraying plant protection chemicals in farmers' fields without properly understanding the intricacies involved in the use of pesticides. It is imperative to develop scientific data to enable generation of standard operating protocols for drone usage in rice.

This study was taken up by PJTSAU as an innovative approach to promote modern agricultural practices and hope that this book adds to the knowledge generated so far on drones. I commend the efforts of research team for bringing out this book.

Hyderabad
10th Dec, 2022

(R. JAGADEESHWAR)

Chapter- 1

INTRODUCTION

Farming in India is critical to global agricultural crop production and food security. According to the “Agriculture in 2050 Project”, the 7.8 billion world population is projected to increase @ ~76 million per annum, increasing by 28% to reach ~10 billion by 2050. Consequently, the global food demand will require a 60% boost in agricultural food production *i.e.,* 8.4 billion tonnes to 13.5 billion tonnes a year by 2050 (Hunter *et al.,* 2017). Similarly, population is rising in India; it is currently 17.63% (1.375 billion) of the total world population and is predicted to increase to 1.7 billion (+23.6%) by 2050. India will surpass China, as the world’s most populous nation by 2027 (UN, 2019). In India, if there is no change in policy, the demand for food grains including pulses is expected to rise by 49.6% in the next three-decades (Chand, 2012). Achieving that level of production from an already seriously depleted natural resource base will be impossible without profound changes in our food and agriculture production systems. We need to expand and accelerate the transition to sustainable food and agriculture, which ensures world food security, provides economic and social opportunities and protects the ecosystem services on which agriculture depends.

In 2015, the terms “Fourth Industrial Revolution or 4IR” (Lejon and Frankelius, 2015) or “Agriculture 4.0” were proposed. The Fourth Industrial Revolution, or 4IR, refers to the imminent revolutionary era in which information and communication technology (ICT) will converge. The revolution will spark new technological innovations in six areas: artificial intelligence (AI), robotics, Internet of things (IoT), unmanned aerial vehicles, three-dimensional printing and nanotechnology. The 4IR will include a variety of new innovative technologies that use big data to incorporate the physical, biological, and digital worlds in a way that will affect all sectors of life including agriculture. Accepting this reality, developed countries such as the USA and Japan are trying to solve agricultural issues through mechanization, automation, and modernization. The 4IR will serve as the opportune time to accelerate the scale and commercialization of agriculture.

In response to this trend, future agriculture is expected to evolve into high-tech agribusiness activity or smart farming that emphasizes the use of sophisticated monitoring & sensing equipment (sensors, satellites, robotics, unmanned aerial vehicles *etc.,*), AI, big data analytics, precision equipment & tools in the cyber physical farm management cycle to create a new era of super fusion. This is encompassed by the phenomenon of big data, massive volumes of spatial and temporal information of crops with a wide variety that can be captured, analysed and used for decision-making. Finally, the era will evolve multifaceted economic, social, and ethical values fused with various industries and expressed in business models (Lee, 2017). As a result, growers are turning to smart farming to address complex challenges of climate change, water scarcity, declining soil health, commodity price volatility, rising input prices *etc.*

Unmanned aerial vehicle (UAV) or drone (dynamic remotely operated navigation equipment), when including the whole system, unmanned aircraft systems (UAS), is a typical example of the 4IR occurring in the present. UAS can help farmers cut down production costs through efficient use of resources (agrochemicals, fertilizers, soil fertility assessment, irrigation management *etc.,*), produce higher yields with better quality, improve farm profitability, and also has environmental benefits. It is highly beneficial for the economy to have a competitive agricultural sector with high quality standards.

Chapter- 2

CROP LOSSES DUE TO PESTS AND PATHOGENS

With the adoption of monocultures, indiscriminate use of fertilizers, water & agrochemicals, changing climate and agroecological conditions, pest and pathogen outbreaks in agroecosystems are becoming more frequent, increasing the threats to crop production. For example, outbreaks of planthoppers (Chander *et al.,* 2003; Bottrell and Schoenly, 2012; Prakash *et al.,* 2014; Anonymous, 2018) and swarming caterpillar (Tanwar *et al.,* 2010) on rice are noticed every now and then owing to congenial weather exacerbated by excessive nitrogenous fertilizers, closer spacing and indiscriminate insecticide use, leading to the destruction of natural enemies in Southeast Asia (Way and Heong, 1994). Neck blast in Karnataka during periods of unseasonal rainfall (Chethana *et al.,* 2016) and bakanae (Bashyal *et al.,* 2014, Gupta *et al.,* 2015) occurrence across basmati growing tracts are diseases of rice creating havoc. The fall armyworm (FAW) invaded India on maize during May 2018 initially in Karnataka, and spread across all maize growing states. Rugose spiralling whitefly (RSW), first noticed on coconut from Tamil Nadu and Kerala in 2016, later spread to Andhra Pradesh, Karnataka, Goa and Assam, through infested seedlings and transportation of plant materials (CPCRI, 2019). The harmful pest, RSW, was also found quickly spreading from coconut to surrounding oil palm plantations in Telangana and Andhra Pradesh (Selvaraj *et al.,* 2019) affecting over 50000 acres of oil palm plantations causing severe economic losses to farmers due to fall in Fresh Fruit Bunches (*FFB) yield* by 35 – 40% (Kumarnath, 2020). India witnessed an upsurge of desert locust in 2020 with their swarms entering Rajasthan, Madhya Pradesh, Uttar Pradesh, Punjab, Haryana, Gujarat, and Telangana between May and June. Cassava mealy bug (CMB) is the latest invasive insect first observed in 2020 at Thrissur, Kerala (Joshi *et al.,* 2020).

The UN Food and Agriculture Organization estimates that in developing countries, pests, weeds and diseases destroy about 37 – 40 per cent of crops, while they are still in the fields and 6 to 7 per cent of them after the harvest (Cao, 2015; Devi *et al.,* 2017). In Africa and Asia, the pre-harvest losses are estimated at 50 per cent. A recent study in 67 countries over the main producing regions of the world for the five major crops with good coverage suggest that yield loss (range) estimates were 21.5% (10.1–28.1%) for wheat, 30.0% (24.6–40.9%) for rice, 22.5% (19.5–41.1%) for maize, 17.2% (8.1–21.0%) for potato and 21.4% (11.0–32.4%) for soybean (Savary *et al.*, 2019). Another study reports that, the extent of yield losses in rice grain yield were 27.9% by pests, 15.6% by diseases and 37% by weeds (Mondal *et al.,* 2017). During each cultivation cycle of agricultural and horticultural crops, production and productivity losses of ~15.7 per cent occur in India owing to pests (Dhaliwal *et al.,* 2015) accounting to ~US$ 36 billion. The crop damage caused by insects is highest, followed by pathogens and weeds. Consequently, the use of agrochemicals in agriculture has been an integral part of crop production in many regions including India, often at very high levels and unscientific pattern of application (Devi *et al.,* 2017). The role of pesticides in augmenting agricultural output has been well perceived and these have been considered as essential inputs in modern agricultural production.

Currently an estimated ~3.6 million tonnes of crop protection chemicals are applied globally per year (Pretty and Bharucha, 2015); out of which 47.5% are herbicides, 29.5% are insecticides, 17.5% are fungicides and 5.5% are other pesticides (De *et al.,* 2014), with serious, negative impacts on ecosystems (Mahmood *et al.,* 2016) and human health (Blair *et al.,* 2014). Whereas, in India a total of 292 pesticides were registered for plant health management and per hectare consumption of pesticides in the country is on rise (600 g/ha) after 2009 – 10 (DPPQ, 2020). Among the pest control chemicals, insecticides dominate the industry with 65 per cent of consumption, followed by herbicides (16%), fungicides (15%) and others (4%) (Devi *et al.,* 2017). Injudicious use of pesticides has led to problems of resistance (Fand *et al.,* 2019; Dhaliwal and Koul, 2010), resurgence and residues.

Chapter- 3

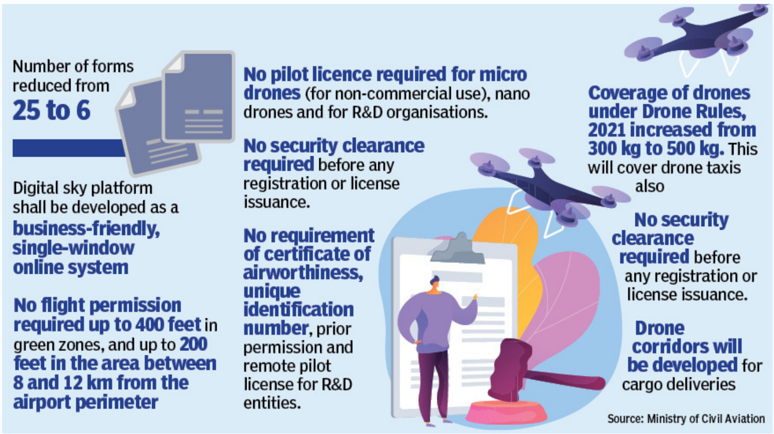
CONVENTIONAL PESTICIDE SPRAYING

Although increases in food grain production in India have been due to several factors, including the use of better plant varieties and seeds, irrigation, fertilizers, agrochemicals (pesticides, fungicides and herbicides), and farm machinery, agrochemicals have been an integral part of the process by reducing crop losses caused by insect pests, diseases and weeds (Bernardes *et al.,* 2015; Lamichhane, 2017). In the developed world about one-third of agricultural production is attributed to the use of agrochemicals (Tudi *et al.,* 2021). Without the use of agrochemicals, it is estimated that there would be a 78% loss of fruit production, a 54% loss of vegetable production, and a 32% loss of cereal production (Lamichhane, 2017). Thus, pesticides are indispensable in agricultural production and have made a significant contribution to alleviating hunger and providing access to an abundant supply of high-quality food to the growing population (Bernardes *et al.,* 2015; Lamichhane, 2017).

When pesticides are sprayed on crops, only a small amount of the applied pesticide displays a protective role to fight against crop pests and diseases. In contrast, a large amount of pesticide owing to either over application or use of inefficient spraying equipment, reaches the non-target areas, resulting in severe environmental pollution, including soil, water & air pollution (Damalas and Eleftherohorinos, 2011; Tudi *et al.,* 2021). In some crops such as cotton, chillies *etc.,* farmers spray pesticides 10 – 20 times, while in most field crops *viz.,* rice, wheat, maize, pulses *etc.,* spraying is limited to 1 – 5 times during the growing season. Further, pesticide application corresponds to a most considerable portion of the production cost with annual crops (Kim *et al.,* 2017). The main spraying equipment used in conventional farming (>90%) in many Asian countries including India are manually operated air-pressure knapsack sprayer, powered knapsack sprayer and mist-blower, rocker sprayer and foot sprayer for orchards, tractor mounted boom sprayer, and power tiller mounted orchard sprayer (Fig 3.1; Yang *et al.,* 2018). Spraying technology aims to effectively and economically apply the precise quantity of the chemical to the set target pest with minimum threat for the environmental pollution (Baio *et al.,* 2018).

Traditional spraying equipment are laborious, time consuming and unsuitable to diverse farming situations. For example, the brown planthopper, *Nilaparvata lugens* is a typical sap-sucking insect usually infesting rice crop during the later stages of crop growth. At this time, leaves of the rice canopy overlap, making it inconvenient for crop spraying using a conventional ground-based knapsack sprayer. Moreover, it is difficult to permeate the lower-middle parts of the rice canopy where rice brown planthoppers are often found, seriously hampering the rice yield (Sheng *et al.,* 2002). Due to the harsh walking conditions in flooded field conditions, operating knapsack sprayers is very difficult, time consuming and labour intensive. High volume spraying using traditional ground-based sprayers causes pesticide wastage (Zhang *et al.,* 2011). For example, while assessing the spatial pesticide spraying deposition distribution in a wheat field, about 20% to 30% gets wasted in the form of pesticide spray drift to non-target areas due to the flow of air (Wang *et al.,* 2016). However, spray drift may be influenced by many factors such as equipment and technology, spray characteristics, operator skill and performance (Antuniassi, 2015) and microclimatic factors such as wind speed, direction, relative humidity and temperature (Baio *et al.,* 2019). Further, pesticide applications using knapsack sprayer and tractor mounted sprayer models generally led to high chemical exposure of the operators (Zhang *et al.,* 2011; Damalas and Koutroubas, 2016; Cao *et al.,* 2017) and postural discomfort (Ghugare *et al.,* 1991). The World Health Organization (WHO) estimated one million cases of ill effects when spraying the pesticides in the cropped field manually. Spray drift not only causes loss of spray liquid but also poses risk for the operator, environment and residents (Zhang *et al.,* 2018). On the other hand, alternative spraying equipment such as self-propelled boom sprayer equipped with horizontal spray boom was reported to have relatively higher working efficiency, lower chemical exposure and higher deposition (Sanchez-Hermosilla *et al.,* 2012). However, the undulated terrain coupled with steep slopes, predominantly small size farm holdings (1.08 ha) with separated plots, and wet field conditions during the rainy season limit the use of boom sprayers in India. Moreover, the operational farm size is increasing with the growth of farmer producer organisations (FPOs), agricultural co-operatives, land leasing and contract farming owing to large scale government incentives, while the labour force is declining by rapid urbanization and rural–urban migration (Bhagat, 2017; Yang *et al.,* 2018) leading to a situation where in the conventional manual operated and labour-intensive spraying equipment types are no longer suitable and relevant for crop protection in intensive diversified production systems. Thus, conventional agricultural pesticide application practices have developed a contradiction among the yield enhancement, cost effectiveness and environmental protection (Dou *et al.,* 2018). Therefore, to make agriculture more productive, profitable and sustainable in the face of rising costs, rising standards of human and environmental health, and climate change, the best combination of available spraying technologies has to be used for crop protection (Mohanty *et al.,* 2013).

Fig. 3.1 Spraying equipment for pest control used in India and Unmanned Aerial Vehicle spraying



Number of forms reduced from **25 to 6**

Digital sky platform shall be developed as a **business-friendly, single-window online system**

No flight permission required up to 400 feet in green zones, and up to **200 feet in the area between 8 and 12 km from the airport perimeter**

No pilot licence required for micro drones (for non-commercial use), nano drones and for R&D organisations.

No security clearance required before any registration or license issuance.

No requirement of certificate of airworthiness, unique identification number, prior permission and remote pilot license for R&D entities.

Coverage of drones under Drone Rules, 2021 increased from 300 kg to 500 kg. This will cover drone taxis also

No security clearance required before any registration or license issuance.

Drone corridors will be developed for cargo deliveries

Source: Ministry of Civil Aviation

Fig. 3.2 Highlights of Drone Rules, 2021

Effective pest control depends on proper application (spraying) practices. Foliar applied insecticides that work primarily through ingestion rely on accurate and adequate spray coverage to maximize key insecticidal attributes and minimize losses. However, with conventional manual and tractor-mounted spraying equipment the effective utilization of applied pesticides that are sprayed on the crops is only around 20 – 30% and the remaining 70 – 80% goes as run-off, leaching, evaporation, and drift that cause soil and aquatic pollution as well as deteriorating the quality of the crop produce (Markle *et al.,* 2016; Torrent *et al.,* 2017). Therefore, there is a need for optimising pesticide delivery to improve efficacy and efficiency, whilst minimising the risk of both exo-drift downwind to neighbouring land and endo-drift losses within a treated field. Spraying equipment and technologies have been undergoing continuous evolution to overcome the limitations in conventional spraying technology (Gil *et al.,* 2014). In recent years, an innovative UAV-based aerial spraying approach is proposed for application of crop protection products with a wide array of benefits that include high pesticide use efficiency, reduced labour costs, saving of time and energy, quick response time, vast and uniform coverage of area, as well as environmental safety (Meng *et al.,* 2018; Shamshiri *et al.,* 2018, Li *et al.,* 2019).

In this background, Ministry of Agriculture, Coorperation & Farmers Welfare, Government of India released Standard Operating Protocols on use of drones for spraying of pesticides to accelerate mechanization in crop protection, which in turn would increase efficiency and efficacy of applied agrochemicals for pest control by reducing time, volume of water and quantity of chemical and manpower required for spraying, and minimizing drift to non-targeted areas to protect environment along with human exposure to hazardous chemicals (GOI, 2021). In addition, the Ministry of Civil Aviation notified the updated Drone Rules 2021, replacing the highly critiques UAS Rules released in March 2021. The liberalized Drone Rules 2021 are more permissive and are expected to remove all unnecessary operational and entry barriers and create a strong drone ecosystem in the country to make India a global hub for drones by 2030.The highlights of Drone Rules, 2021 are given in Fig. 3.2.

Chapter- 4

UNMANNED AERIAL VEHICLES (DRONES) – INTRODUCTION AND REVIEW

4.1 Unmanned Aerial vehicle

An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft that can operate autonomously or can be operated remotely without a human pilot on board. The more commonly used terms are Remotely-Piloted Aircraft Systems (RPAS) and Unmanned Aircraft Systems (UAS) (Hassanalian and Abdelkefi, 2017). UAS offers opportunities to meet the needs and challenges of today's agricultural food value chain and research. UAS consists of an UAV, which uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a payload, and a ground control station (GCS) for mission planning and flight control. The UAS are classified in India, based on the maximum all-up weight including payload as (i) Nano: less than or equal to 250 g; (ii) Micro: greater than 250 g and less than or equal to 2 kg; (iii) Small: greater than 2 kg and less than or equal to 25 kg; (iv) Medium: greater than 25 kg and less than or equal to 150 kg; and (v) Large: greater than 150 kg.

Compared to conventional agricultural manned aircraft, UAVs does not require a special airport and have advantages, such as good mobility (Bae and Koo, 2013; Qin *et al.,* 2016), low weight, flexible movement, lower operational cost and complexity, less dependence on weather conditions, higher spatial resolution, and shorter revisit time (Zhang and Kovacs, 2012; Qiu *et al.,* 2013; Giles and Billing, 2015; Sankaran *et al.,* 2015). UAVs are also more adaptable for spraying at low altitudes due to geographical restrictions (Zhang *et al.,* 2014; Lan *et al.,* 2008; Fritz *et al.,* 2007). In addition, the application of obstacle avoidance technology and terrain following technology has improved the safety and accuracy of agricultural drone operations (Lan and Chen, 2018; Wang *et al.,* 2019a; Lan *et al.,* 2017). Hazards of pesticide contamination and exposure of humans (in most cases the operator) due to lack of protective clothing, skill and ignorance still remains the most often raised and the most salient consequence of malpractice in conventional pesticide application practices. On the other hand, in aerial spraying using drones the operator is away from the pesticide tank and spray drift, which could minimize the risks of pesticide contact and exposure to the applicator. In addition, there is high operating efficiency in UAVs. The average single operation can reach 0.8–2.8 hectares under different power capacities (Lan and Wang, 2018). Agricultural aerial spraying by drones is often the most economical and rapid method for providing efficient and effective applications for crop pest control, allowing for quick responses to sudden pest outbreaks (Chen *et al.,* 2017a). Moreover, when compared to tractor mounted ground plant-protection machinery, drones can cover large field blocks without any soil compaction and damage to soil physical structure, which is very important (Lan *et al.,* 2017; Chen *et al.,* 2021). Drones can also be more conveniently adapted to the small complex field plots across India's diversified crops and specialty crops such as tea, coffee and orchard crops cultivated on undulated terrain and steep slopes (Huang *et al.,* 2013; Liao *et al.,* 2015; Chen *et al.,* 2017b; Sarri *et al.,* 2019). Labour costs for aerial spraying by drone are also low, and crops and the physical structure of soil are not damaged by drone equipment (Wen *et al.,* 2018). Furthermore, initial results on aerial spraying using drones indicate reduced pesticide application by 15–20%, and it can be used as an important technical support for a reduction program for chemical fertilizers and pesticides (Xue *et al.,* 2016; Jorge *et al.,* 2019).

Compared with ground equipment, the biggest difference is the spray volume of pesticide used per unit area. The average spray volume used in different ground-based sprayers (knapsack-type sprayer, boom sprayer, orchard sprayer *etc.,*) and various crop types (field crops, vegetables, orchard, plantation crops *etc.,*) varies from 300–1000 L/ha, while the average spray volume application by drone ranges from 15–40 L/ha depending on the model and payload capacity (Qin *et al.,* 2016; Wang *et al.,* 2019b; Xin *et al.,* 2018; Lou *et al.,* 2018). Drones designed for agrochemical application also differ from those used for optical remote sensing, monitoring and other data collection not only in terms of carrying of the chemical payload but also the mechanisms and power for pumping, agitation, spraying and other mechanical requirements. Consequently, drones used for physical actions of seeding and spraying are typically larger aircrafts with greater lift and flight endurance capacity, requiring more energy dense power sources, such as combustion engines and conventional fuel, for propulsion of the vehicles. Moreover, UAVs can also perform site-specific farm management with high precision (Chen *et al.,* 2021). For comparison, the spraying related parameters for traditional spraying equipment and drones are given in Table 4.1. Several researchers opine that using drones for aerial spraying of agrochemicals and fertilizers can help relieve productivity challenges typically encountered by manual labour and operators of traditional ground-based farming equipment. Today, in several Asian countries the aerial spraying using agricultural drones is the most preferred method for plant protection (Lan and Chen, 2018). According to the Association for Unmanned Vehicle Systems International (AUVSI), 80% of UAVs will be utilized for agricultural purposes in the near future. The benefits of aerial spraying by drones *vis-à-vis* ground-based conventional sprayers are summarized in Table 4.2.

Table 4.1 Aerial spraying parameters for traditional spraying equipment *v/s* drones

Type	Spray Volume (L/ha)	Nozzle type	No. of Nozzles	Tank capacity (L)	Flight height (m) above crop canopy	Flight speed (m/s)	Spray width (m)	Field capacity (ha/hour)	Suitability
Drone	15–40	Flat fan	4	5 – 20	1.5 – 3.0	3 – 5	3 to 5	2.0	Small & large fields, field crops, fruit orchards, vegetables, flowers, plantation crops, specialty crops like tea and coffee raised on undulated and steep slopes
Knapsack sprayer	300–500	Flat fan / Hollow cone	1	10 – 16	0.6 – 1.0	0.5-1.5	< 0.5	0.12	Small field plots, field crops and vegetables
Taiwan sprayer	300–500	Solid cone / Hollow cone	1	20	0.6 – 1.0	0.5-1.5	< 0.5	0.19	Small field plots, field crops and vegetables
Tractor mounted boom sprayer	300–500	Flat fan / Hollow cone	24	400	0.45 – 0.75	0.83	12	2.08	Row field crops like cotton, maize, soybean, oilseeds etc
Tractor mounted orchard sprayer	1000	Flat fan / Hollow cone	10	1000	1.0 – 6.0	1.2	10	1.38	Fruit Orchards

Source: Compiled from different sources (FICCI, 2020; Wang et al., 2018; Technical specifications of different sprayers etc.,)

4.2 UAV (Drone) Aerial Spraying Technology – Brief Review

Adoption of agriculture drones is growing exponentially particularly in China, Japan and USA over the past few years owing to their great practical value, broad prospect of application scope, and likelihood to deliver massive production and economic benefits to farmers. Aerial spraying of agrochemicals and fertilizers by agriculture drones on crops can alleviate labour constraints, reduce chemical exposure to human (operator), increase working efficiency and control efficiency in agriculture sector while improving agronomic sustainability and crop yields. In view of this, aerial spraying by drones has attracted plenty of scholar's attention and subject of recent research. However, very limited scientific evidence is available in India concerning crop specific "Standard Operating Protocols" for field application by small holder farmers.

The flying and spraying parameters of drones significantly influence droplet deposition and spray drift. For example, drone types and the flight parameters *viz.*, flight accuracy, flight height, flight velocity, nozzle type, spray mixture, spray volume, swath or spray width, downwash effect, *etc.*, significantly influence the droplet density, deposition characteristics of droplets, spray drift, control efficiency and working efficiency (Wang *et al.*, 2019c; da Cunha *et al.*, 2021). The uniformity of droplet deposition distribution and control efficacy is also affected by the crop species, morphological structure of the crop plants (Tang *et al.*, 2018) and meteorological conditions (Chen *et al.*, 2017b; Hunter *et al.*, 2020).

Therefore, several initial studies were concentrated on optimizing the chemical application parameters for aerial spraying using drones. In general, spray applications have been mostly tested between 1.0 m to 3.0 m of flight height and 1.0 m/s to 7.0 m/s of flight velocity, as can be observed in the works of Liao *et al.*,(2019), Wang *et al.*, (2020), Ahmad *et al.*, (2020), and Chen *et al.*,(2020a). Whereas, Qin *et al.*, (2016) screened the operational aerial spray parameters for controlling rice brown planthopper using HyB-15L drone (Gao Ke Xin Nong Co. Ltd., Shenzhen, Guangdong, China) and found that when the flight height was1.5 m and the flight velocity was 5 m/s, the droplet deposition in the lower layer of the crop was the largest, and the uniformity (CV = 23%) was the best.

Table 4.2 Aerial drone spraying *v/s* conventional spraying

Benefits of aerial spraying by drones	Challenges with conventional spraying
• Quick, easy and highly efficient	• Time consuming, laborious and efficiency varies with skill of the operator
• No / minimal operational exposure. Safer to operate	• Hazard of pesticide contamination and exposure of the operator
• Less water consuming (15 – 40 L/ha)	• More water consuming (500 L/ha)
• Precision spraying and uniform coverage	• Only small areas can be covered
• During pest disease outbreak, larger areas can be covered with in short span, leading to efficient crop protection	• During sudden pest/disease outbreak inefficient crop protection due to more spraying time
• Adaptable to undulated terrain, steep slopes, wet muddy fields, and inaccessible heights such as tall trees (oil palm, coconut etc)	• Can be operated efficiently up to certain height only
• Higher return on investment.	• Low return of investment.

Source: FICCI, 2020

On the other hand, Lou *et al.,* (2018) studied the effect pesticide application with drones on cotton aphids and spider mites and found that the droplet uniformity, the droplet coverage rate, and the deposition were satisfactory at 2 m flight height. This may be because, at reduced flight height of 1.5 m a strong downward swirling airflow generated below the rotor causes the plants to sway substantially, and the droplet density and deposition on the canopy is markedly affected (Chen *et al.,* 2017b; Zhang *et al.,* 2021). Hussain *et al.,* (2019) evaluated the distribution uniformity of a hexacopter flying at different heights and found good distribution uniformity at heights of 1.5 m and 2.0 m. However, the authors noted that at greater heights of 3.0 m, there was a worsening of uniformity, attributed mainly to the crosswind's negative effect. The swirling airflow below the rotor of a multirotor aircraft was found to differ significantly with variation in flight height (1.5 m to 3.5 m) and flight speed (2.0 m/s to 5.0 m/s) (Zhang *et al.,* 2020a). Zhang *et al.,* (2020b) found that under comprehensive consideration of the density, uniformity, and penetration of droplet deposition, the optimal spraying parameters were 3 m of flight height, 4 m/s of flight velocity and 15 L/ha of spray volume, which could be used as a reference parameter for aerial drone spraying in sugarcane crop. Liao *et al.,* (2019) observed improved performance of drones with the best working speeds ranging between 1.5 m/s and 3.8 m/s for defoliation of leaves in cotton. Evaluation of the deposition swath of a DJI AGRAS MG-1 octocopter drone suggested that the flight speed did not influence the swath width, but the flight height interfered with this parameter (Martin *et al.,* 2019). The effective deposition range (considering a CV of 25%) varied from 4.6 to 7.6, depending on the operational condition. These initial results confirm the feasibility of ultra-low-volume spraying using drones for pest and disease control of crops and led to the popularization and application of UAV in crop protection (Lan and Chen, 2018).

However, spraying volume in drone aerial applications is still limited by the load capacity of the tank. Compared with ground equipment, the biggest difference with drone spraying is the volume of pesticide sprayed per unit area. The average application of ground application equipment (knapsack-type sprayer) in irrigated dry crops such as wheat, cotton, groundnut *etc.,* is 350–500 L/ha, and 500 – 750 L/hais used by tractor-mounted boom sprayer in rice, while the average application of drone is 15 – 40 L/ha (Qin *et al.,* 2016; Wang *et al.,* 2019c; Xin *et al.,* 2018; Wang *et al.,* 2019a; Lou *et al.,* 2018). Spraying limited volumes while ensuring proper application coverage and pest control is a challenge for UAV applications. Wang *et al.,* 2019(b) studied the effects of spraying volume on UAV application efficacy, and the results showed that better control of wheat diseases and insect pests were achieved when using coarse droplet size and a spray volume of >16.8 L/ha. Xin *et al.,* (2018) reported that with the increase of the spraying volume of UAV, the residual volume of defoliant in cotton increased. When the spraying volume was lower than 17.6 L/ha, the residual volume was the lowest.

The control efficacy on pests and diseases is one of the most important evaluation indices of chemical application by drones. The control efficacy with aerial spraying using drones ideally should be compatible/similar to that of conventional spray application methods, considering the advantages and challenges of drone application. Most studies compare this application method with the backpack sprayer, which is widely used in smallholder farms in developing countries worldwide. The control efficacy of drone aerial spray with 70% Imidacloprid on wheat aphids was 70.9% and was comparable with conventional high-volume sprayers (Wang *et al.,* 2019c). On the other hand, Qin *et al.,* (2016) studied the control efficacy of HyB-15L drone by spraying Chlorpyrifos, (@ 432 g a.i./ha, spray volume rate of approximately 15 L/ha against brown planthoppers and found that the insecticidal efficacy was 92% and 74% at 3 and 10 days after spraying insecticide, respectively. Moreover, both the insecticidal efficacy and the persistence period were greater than those achieved with a conventional stretcher-mounted sprayer (@ 432 g a.i./ha at spray volume rate of approximately 750 L/ha), indicating that UAV had a low-volume and highly concentrated spray pattern to enhance the duration of efficacy (Qin *et al.,* 2016).

On the premise of guaranteed control efficacy, the working efficiency is another important evaluation index of drone aerial spraying. Considering the limited payload and the flight range, the effective spray work rates of 2–5 ha/hr were achieved in a vineyard with a gasoline-powered UAV (RMAX, Yamaha motor Co., Cypress, CA, USA) (Giles and Billing, 2014). The working efficiency of different UAVs in the grain-filling stage of wheat was studied by Wang *et al.,* (2017), with the daily working area ranging from 13.4 to 18.0 ha in 8 hours. Later, while assessing the performance of different conventional sprayers and UAV, Wang *et al.,* (2019c) observed that the working efficiency of the UAV sprayer was 4.11 ha/hour, which was *1.7, 2.6, and 20.0* times those of self-propelled boom sprayer, knapsack mist-blower and electric air-pressure knapsack sprayer, respectively. This is the greatest practical advantage of the UAV sprayer under field conditions.

4.3 Genesis of Drone Application and Research in PJTSAU

1

Aerial mapping and digitization of university properties and lands at Rajendranagar main campus, Agricultural Research Stations and KVKs of Central Telangana Zone were completed in the 2019, after an MOU with AEGIES Drone manufacturers on 27.9.2018.

2

Initiation of research on "Assessing of spray fluid requirements for aerial spraying using drones in rice crop" at Rice Research Centre, Rajendranagar on 21st February, 2019 (Fig. 4.1).

3

Observation trial on "Evaluation of performance of drone aerial spraying and traditional ground-based knapsack spraying in managing safflower aphids" at Agriculture Research Station, Tandur during November, 2019 (Fig. 4.1).

4

Organized a brain storming session on "Drone-based applications in agriculture" at University Auditorium, Hyderabad on 9th January, 2020 involving industry representatives, farmers, scientists from PJTSAU and IIIT, NGOs *etc.,* under the chairmanship of Honourable Vice Chancellor, PJTSAU

5

MOU signed between PJTSAU and Aviation Department, MIT, Anna University on 9.1.2020.

6

Launching of "Network Project on Evaluation and Standardization of Aerial Spraying Parameters using Drones in Major Field Crops" by Sri. Jayesh Ranjan, Principal Secretary (Industries & Commerce and IT) and Dr. B. Janardhan Reddy, APC & Secretary (Agriculture), Government of Telangana at PJTSAU on 24th September, 2020 (Fig.4.2).

7

MOU signed between PJTSAU and various drone companies *viz.,* Marut Dronetech Pvt. Ltd. and Thanos on 5.12.2020.

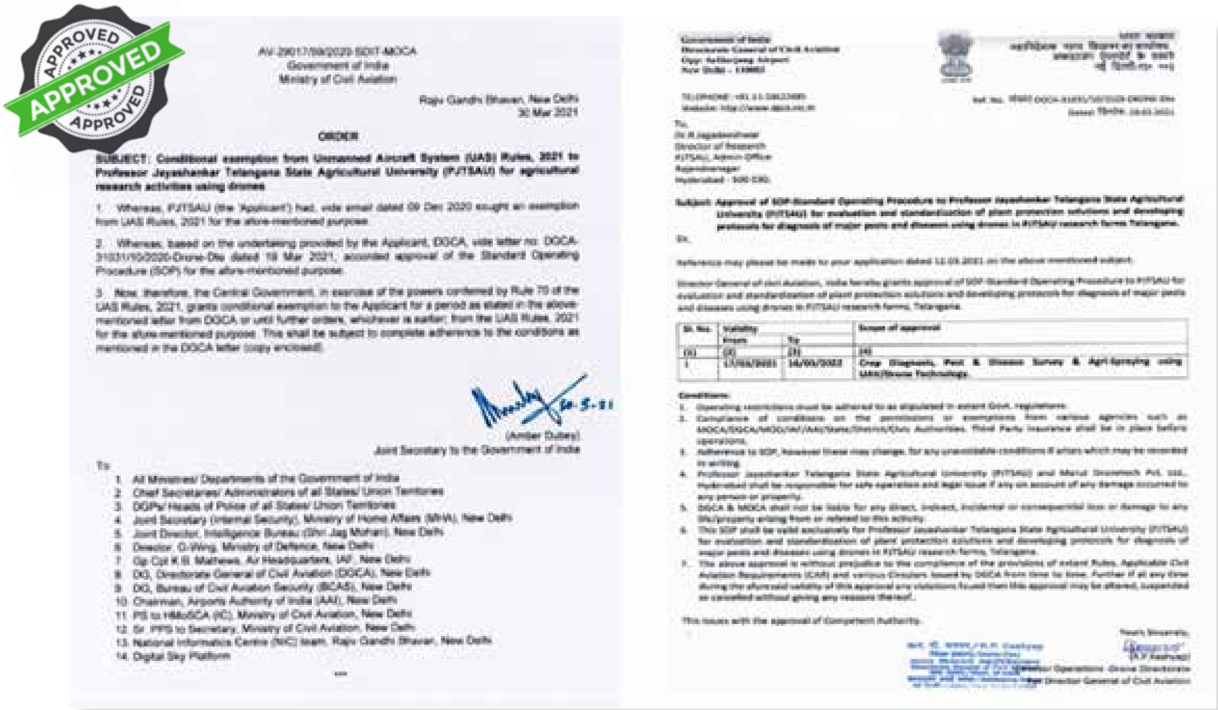
Fig. 4.1 Genesis of drone application and research at PJTSAU

Fig. 4.2 Launching of Network Project on "Evaluation and Standardization of Aerial Spraying Parameters using Drones in Major Field Crops"

DRONE PARTNER - MARUT DRONETECH PVT LTD., HYDERABAD

4.4 DGCA Approval to PJTSAU for Conducting R&D work on Aerial Spraying of Pesticides Using Drones

The Professor Jayashankar Telangana State Agricultural University was the 1st State Agricultural University in the country to get approval from Director General of Civil Aviation (DGCA), Government of India to carry out R&D work on "Evaluation and standardization of aerial spraying protocols using drones for control of major pests and diseases in major crops" at PJTSAU research farms located in Telangana State (Fig.4.3 and Fig. 4.4).



AV-29017/59/2020-SDIT-MOCA
Government of India
Ministry of Civil Aviation

Rajiv Gandhi Bhawan, New Delhi
30 Mar 2021

ORDER

SUBJECT: Conditional exemption from Unmanned Aircraft System (UAS) Rules, 2021 to Professor Jayashankar Telangana State Agricultural University (PJTSAU) for agricultural research activities using drones

1. Whereas, PJTSAU (the 'Applicant') had, vide email dated 09 Dec 2020 sought an exemption from UAS Rules, 2021 for the afore-mentioned purpose.

2. Whereas, based on the undertaking provided by the Applicant, DGCA, vide letter no. DGCA-31031/10/2020-Drone-Dte dated 18 Mar 2021, accorded approval of the Standard Operating Procedure (SOP) for the afore-mentioned purpose.

3. Now, therefore, the Central Government, in exercise of the powers conferred by Rule 70 of the UAS Rules, 2021, grants conditional exemption to the Applicant for a period as stated in the above-mentioned letter from DGCA or until further orders, whichever is earlier, from the UAS Rules, 2021 for the afore-mentioned purpose. This shall be subject to complete adherence to the conditions as mentioned in the DGCA letter (copy enclosed).

30.3.21
(Amber Dubey)
Joint Secretary to the Government of India

To:
1. All Ministries/ Departments of the Government of India
2. Chief Secretaries/ Administrators of all States/ Union Territories
3. DGPs/ Heads of Police of all States/ Union Territories
4. Joint Secretary (Internal Security), Ministry of Home Affairs (MHA), New Delhi
5. Joint Director, Intelligence Bureau (Shri Jag Mohan), New Delhi
6. Director, G-Wing, Ministry of Defence, New Delhi
7. Gp Capt K B Mathews, Air Headquarters, IAF, New Delhi
8. DG, Directorate General of Civil Aviation (DGCA), New Delhi
9. DG, Bureau of Civil Aviation Security (BCAS), New Delhi
10. Chairman, Airports Authority of India (AAI), New Delhi
11. PS to HMoSCA (IC), Ministry of Civil Aviation, New Delhi
12. Sr. PPS to Secretary, Ministry of Civil Aviation, New Delhi
13. National Informatics Centre (NIC) team, Rajiv Gandhi Bhawan, New Delhi
14. Digital Sky Platform

Fig. 4.3 DGCA approval for R&D work on aerial spraying using drones for pest and disease control in crops

నమస్తే తెలంగాణ

డ్రోన్ల వినియోగానికి డీజీసీఏ అనుమతి

ఈనాడు

జయశంకర్ వర్సిటీకి డ్రోన్ల వినియోగ అనుమతి

THE NEW INDIAN EXPRESS

DGCA approves Telangana State Agricultural University's request to use drones for research

THE HINDU

First university in the country to get such permission

The Director General of Civil Aviation (DGCA) has approved the standard operating procedure on the use of drone/UAV technology by Professor Jayashankar Telangana State Agricultural University (PJTSAU) here for its its research work on crop diagnosis, pest and disease survey and spraying purposes.

In a first of its kind approval given to a university in the country, the validity of the approval is for one year — up to March 16, 2022. It would help evaluation and standardisation of plant protection solutions and also developing the protocols for diagnosis of major pests and diseases using drone in PJTSAU research farms in Telangana.

Fig.4.4 Press coverage on DGCA approval to PJTSAU

Chapter- 5

RICE CROP – PEST & DISEASE SCENARIO

5.1 Insect Pests of rice and crop losses

Rice *(Oryza sativa L.)* is a staple food for over half of the world population, but serious yield losses are caused annually by insects and diseases (Akhtar *et al.,* 2009; Hu *et al.,* 2014). Rice is grown on over 164.19 million ha which produced over 509.5 million tonnes in 2020-2021. India the second largest producer of rice in the world alone harvested over 44.22 million ha and produced 124.37 million tonnes of milled rice in 2020-2021. Rice is also the predominant food crop of Telangana with a cropped area of 4.24 million ha and a production of 14.57 million tonnes. The crop is the primary source of income and employment of nearly 53.2 per cent farm households in India. Further, households in India are predominantly small and marginal farmers, with an average farm size of 1.08 ha. The increase in the volume of rice production is an immediate requirement in the world (including India) due to rapidly growing populations; however, achieving this task seems challenging due to various obstacles, such as climate change impacts along with managing the different kinds of arthropods pests which attack rice fields. To date, 266 different kinds of herbivores (including non-arthropod species such as rats) have been recorded from rice ecosystems, which directly or indirectly cause rice production losses (BRRI, 2016). However, total number narrows down to only 15–20 species, which are considered as major insect pests that cause significant yield loss when occur in sufficiently large numbers (Fig. 5.1).

Typically, insect pests cause 18% yield loss to rice production and currently control of these arthropod pests solely depends on chemical pesticides (Islam *et al.,* 2003).

Brown Planthopper

Savary *et al.*, (2019) estimated average yield losses in rice to vary between 21 – 41 per cent. Rice yellow stem borer (YSB), *Scirpophaga incertulas* (Walker) is one of the most destructive insect pest of rice found in diverse ecosystems causing significant yield losses – for *e.g.*, 1% each of dead hearts and white ears leads to yield loss of 2.5 and 4.0%, respectively (Muralidharan and Pasalu, 2006). Similarly, the yield losses due to brown planthopper (BPH) were reported to vary between 10 to 90%. The losses due to *N. lugens* in Asia alone have been estimated to be more than 300 million USD annually (Min *et al.*, 2014). The rice gall midge, *Orseolia oryzae* is another important pest of rice across various rice growing states of India with yield losses approximately in the range of 80 million USD in South India alone (Bentur *et al.*, 2003). On the other hand, yield losses due to rice leaf folder ranged from 63 to 80% wherein high-yielding or hybrid rice varieties being more susceptible (Teng *et al.*, 1993). At flowering stage, flag leaf area damage of above 25% by leaf folders resulted in more than 50% unfilled grains over control, indicating direct effect of yield reduction in rice (Padmavathi *et al.*, 2013).

Fig.5.1 Major insect pests of rice

5.2 Diseases of rice and crop losses

Major diseases affecting rice crop are shown in Fig. 5.2. Annual average crop yield losses due to diseases worldwide were estimated to vary between 10–15% (Annegowda *et al.,* 2021). The infection of the panicle base (neck blast) by the blast pathogen until 20 days after heading caused more than 50 percent yield loss. During natural epidemics of blast disease in the wet season, disease incidence ranged from 14 to 27% (above the economic threshold), resulting in yield loss of about 27–35 percent (Rajarajeswari and Muralidharan, 2006). Likewise, yield losses to the tune of 4 – 50% by sheath blight and 20% by bacterial leaf blight were reported (Bhunkal*et al.,* 2015). Further, in recent years, the incidence of stem rot has increased in several rice-growing regions of India (Ladhalakshmi *et al.,* 2012) with yield losses reaching up to 80 per cent. While false smut disease incidence in different regions of India resulted in 0.2–49% yield loss, depending on rice varieties adopted and disease intensity (Dodan and Singh, 1996).

Sheath Blight

Neck Blast

Bacterial Leaf Blight

Grain Discolouration

Fig.5.2 Major diseases of rice

5.3 Droplet parameter studies using drones

Qin *et al.,* 2016 evaluated the influence of spraying parameters, such as operational height and operation velocity of the UAV on droplet deposition on the rice canopy and protection efficacy against planthoppers. The spraying parameters for preventing planthoppers were then optimized. When the spraying height was 1.5 m and the spraying velocity 5 m/s, the droplet deposition in the lower layer was maximized, and the droplets exhibited the most uniform distribution (CV = 23%). The insecticidal efficacy was 92 and 74%, respectively at 3 to 10 days after spraying insecticide.

Chen *et al.,* 2020 studied the droplet deposition and control of planthoppers in rice using UAV with different nozzles and reported that among three nozzle types (LU 110-010, LU 110-015 and LU 110-020) evaluated, LU 110-01 nozzle was the best in terms of droplet density and coverage with control efficacy of 89.4 and 90.8%, respectively against rice planthoppers. Maikaensarn and Chantharat, 2020 have conducted effective analysis of drone use for rice production in Thailand and stated that drone use reduced production losses by 10-15% and water volume by 10 times and chemical dose by 40%.

5.4 Monitoring, detection of insect pests and diseases using drones and studying impact of pesticides in rice

Kitpo and Inoue, 2018 studied the feasibility of early detection of rice diseases using drone and IOT architecture and developed preliminary support system for real time disease detection. Kim *et al.,* 2019 studied the feasibility of using UAVs for aerial sampling of insect populations in rice by developing rotary-wing unmanned aerial vehicle with remote-controlled insect net openings that allows serial sampling at designated altitudes. A total of 21 flights using the unmanned aerial vehicle system captured 251 insects in 6 orders and 22 families at 5, 10, 50, and 100 m above rice fields in South Korea.

Liu *et al.,* 2020 employed UAV-based hyperspectral data to detect rice stress induced by leaf folder during their booting stage and vegetation indices (R550−R531)/(R550+R531) which performed well in estimating leaf-roll rates.

Subramanian *et al.,* 2021 reported that Tamil Nadu Agricultural University, Coimbatore, India, made a maiden attempt to study the efficacy of pesticide spray (fungicide copper oxychloride 53.8% @ 35 g per 16 L/ha against bacterial and fungal diseases) in rice fields using drones during the cropping season of September 2020. A hexacopter type drone (payload 16 L; fuel capacity 3.5 L) was employed to study the application of pesticides in rice fields. Preliminary studies have shown the optimal flying height (3 m), speed (5 m /s−1), swath (4 m), and the area coverage (4 min/ acre−1).

Xu *et al.,* 2014 conducted drift and deposition study with rice seedlings (13cm height), using flight height of 5m, speed of 3m/sec and carrier volume of 15 L/ha. The average deposition on upper canopy was 28% and lower canopy was 26%.

Wang *et al.,* (2020) studied the biological efficacy of UAV based low-volume application of Pyraclostrobin 9% CS @ 80 g/ha against rice blast revealed that 62.7% control efficacy was achieved with spray volume of 18L/ha with adjuvant (methylated seed oil).

Chapter- 6

DEVELOPING STANDARD OPERATING PROTOCOLS FOR DRONE AERIAL SPRAYING FOR PEST MANAGEMENT IN RICE

6.1 Standard Operating Protocols for drone based pesticide spraying

Liquid spray formulations are predominantly used during pesticide spraying with different kinds of sprayers comprising a pump and nozzle to convert the fluid into droplets by creating certain pressure. The success of spray ultimately depends upon the selection of appropriate nozzle which enables uniform droplet distribution to all plant parts and thus droplet spray uniformity plays a crucial role in determining sprayer suitability.

Performance of drone based pesticide spraying is greatly determined by the type of nozzle used, which in turn aids to achieve spray uniformity, desirable droplet size, effective spray width and liquid distribution *etc.*, to avoid drift of droplets. The four major factors that affect the droplet size are tip style, capacity, spraying pressure and spray pattern type. Lower spraying pressure provides larger droplet sizes. Larger spray droplets are produced by flat hydraulic spray tips and smaller droplet sizes are produced by hollow cone.

While choosing the nozzle type (tips), applicants must consider both coverage and drift potential. Drift in turn depends on the droplet size, which influences the penetration performance of spray into the crops and reduces the amount of pesticide spraying per unit area. As a rule smaller droplets will provide better coverage but likely to drift more, while larger droplets are likely to drift less but coverage may be affected which in turn varies depending upon wind speed and direction. Therefore, one has to identify a nozzle type which offers optimum coverage and drifts less, such that it effectively reaches the intended target and also minimizes the environmental consequences.

Apart from these, the effective application of plant protection chemicals using drones (UAVs) depends mainly on several factors that interfere with quality and type of application. Among these, spraying height, drone flight speed, droplet parameters, application rate and spray solution properties, spray volume *etc.,* are important. Therefore, initial studies were conducted to generate information on droplet parameters with different nozzle types operated at different heights. Based on these SOPs further studies were conducted on bioefficacy of drone based pesticide sprays against rice yellow stem borer, whorl maggot, brown planthopper, false smut and grain discolouration. Further, impact of drone based pesticide spraying was also assessed on beneficial fauna (coccinellids, spiders and mirid bugs), avian fauna *etc.,*.

Therefore, a working framework was designed to generate information on the following important aspects which will aid in effective use of drones for pesticide spraying in rice (Fig 6.1).

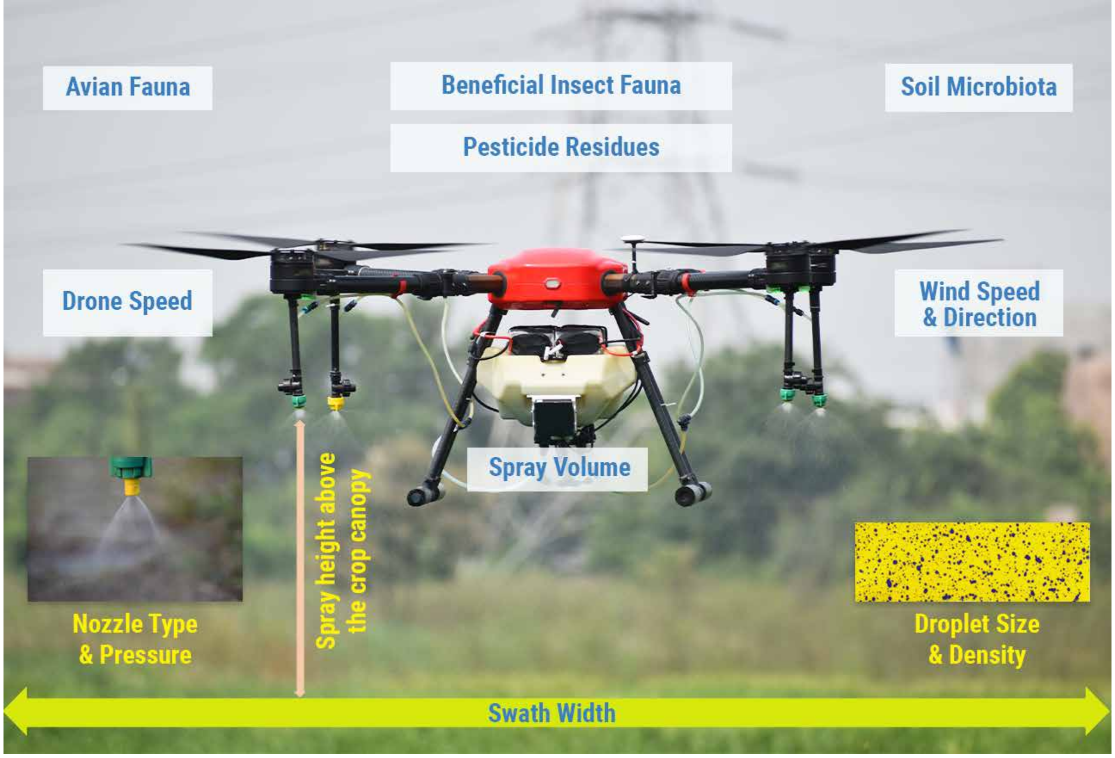


Fig. 6.1 Working framework for developing standard operating protocols (SOPs) for aerial spraying of pesticides by drones in rice

6.1.1 Location

The controlled, randomized and replicated experiments were conducted during *kharif (Vanakalam),* 2020 at Rice Research Centre, Agricultural Research Institute (Fig.6.2), Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana state, India (North Latitude: 17°324254; East Longitude 78°408576; Altitude 542.0 MSL).The test variety of rice was "Telangana Sona (RNR 15048"). The crop was transplanted on 23rd July, 2020 adopting a spacing of 20 cm between rows and 15 cm between plants maintaining a plant population of 33plants/m². The rice crop in the whole test area grew well and consistently. All the standard and recommended agronomic practices were followed uniformly for all the plots.

Fig.6.2 Field view of the rice drone spraying test plots

6.1.2 Spraying equipment

As shown in Fig.6.3, the model of UAV (drone) used in this aerial spraying test was battery motive AGRICOPTER AG 365 with UIN UA00132S1EX (Table 6.1). The UAV was powered by two 22,000 mAH Li-Po batteries. The flying time was 15 min with full tank. The flight speed was 3-5 m/s, and the capacity of the tank was 10 L. The interval of nozzles was 1.2 m and installation angle was 110º. The type of UAV has four hydraulic nozzles, which symmetrically distributed on both sides of the fuselage. The accuracy of the flight height and flight velocity was controlled by the well-trained operator. The flight height was maintained between 2 to 3 m and effective spraying width was between 3 to 4 m depending upon the nozzle type. The same drone was used for conducting drone SOPs and all bio-efficacy studies.

Fig.6.3 Drone spraying model

Table 6.1 Technical specifications of drone used in the experiment

Particulars	Parameter
Model	AGRICOPTER AG 365 with UIN UA00132S1EX
Drone Partner	Marut Dronetech Pvt. Ltd., Hyderabad
All of weight (Max .Pay Load)	23.2 kg
Pay load capacity / volume	10 Litres
Endurance	20 min
Operating Temperature	0 – 45 °C
Power Battery	2 Nos of 22000 mAh
Battery cost	Rs. 35,000 each (approx.)
Battery life	250 cycles
Battery charging time	45 min.
Folding Method	Folding Inward
Dimensions	1920 x1820 x 500 mm
Flight Mode Options	Manual /Semi-Autonomous / Fully Autonomous
Fail safe features	Return To Home, Hovering on signal lost
Spraying width	3 – 5 m (depends on nozzle type)
Max. flying speed	5.0 m / second
Flying speed for aerial spraying	3 – 5 m/second
Pump pressure	1Mpa
Spray system	Centrifugal nozzle
Max .flow velocity	200 – 800 ml/min.
Height above the crop	2 – 3 m
Driving speed	1 – 8 m/s
Operation method	Remote control or mobile
Operating Frequency	2.4 GHz
Number of nozzles	4 Nos.
Nozzle spacing	1.2 m
Spray angle of the nozzle and tip	110º
Spray pressure	20 – 30 PSI
Droplet size	Fine

6.1.3 Treatments for spray deposition measurements

The experiment consisted of five nozzle types (Fig 6.4) *viz.,* XR 11002 VP, TXA 8002 VK, TJ 60-025, TP 8002 VP and TP8002 EVS (M/s. Teejet Technologies, Spraying Systems Co., USA) operated at three flying test heights *viz.,* 2.0 m, 2.5 m and 3.0 m above crop canopy (Table 6.2, Fig 6.4 and Fig. 6.6). These nozzles were drone compatible, operable at different pressures ranging from 15-60 psi, creating different spray patterns (Fig 6.5)

Table 6.2 The nozzles types used for conducting the drone experiments

S. No.	Treatment	Tip No.	Nozzle Type	Spray Angle (°)	Spray Pattern
1	T_1	XR 11002 VP	Extended range	110	Flat fan
2	T_2	TXA 8002 VK	Cone jet	80	Hollow cone
3	T_3	TJ 60 – 025	Twin jet	80	Flood Jet Wide angle
4	T_4	TP 8002 VP	Extended range with cap	80	Air Induction Flat fan
5	T_5	TP 8002 EVS	Visilow	80	Air Induction Flat fan

The treatments were organized in factorial randomized block design with three replications and the plots were well separated by maintaining buffer zone of 5 meters between the treatments. The height of the rice plant usually ranges between 90 – 110 cm. Accordingly, the water sensitive papers (WSPs) measuring 26×76 mm (M/s. Teejet Technologies, Spraying Systems Co., USA) were placed on bamboo pegs at 110 cm (top), 60 cm (middle) and 10 cm (bottom) above the standing water in the paddy field as shown in Fig. 6.7. While placing the WSPs, proper care was taken by wearing the hand gloves to prevent any contact of moisture with the WSPs. A plot size of 150 m² was maintained and three bamboo pegs per treatment were placed randomly at different intervals along the drone fly pathway.

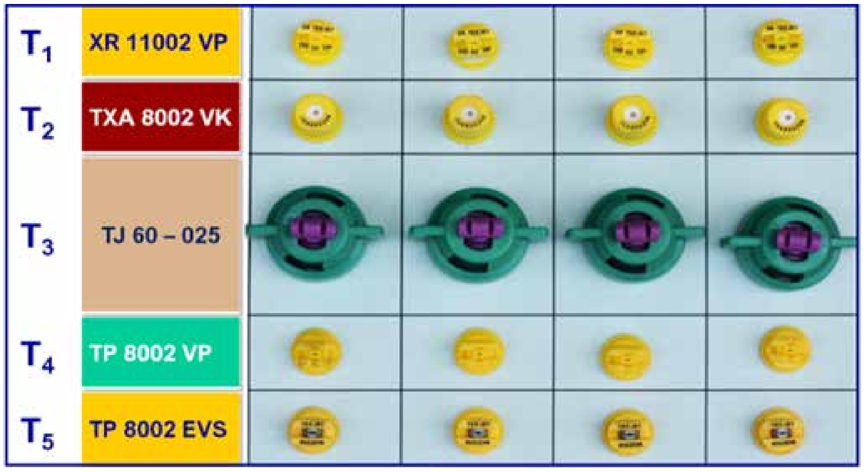


Fig. 6.4 Nozzle types tested in the present study

Fig. 6.5 Nozzle types creating different spray patterns (Source: Teejet Nozzles Catalogue)

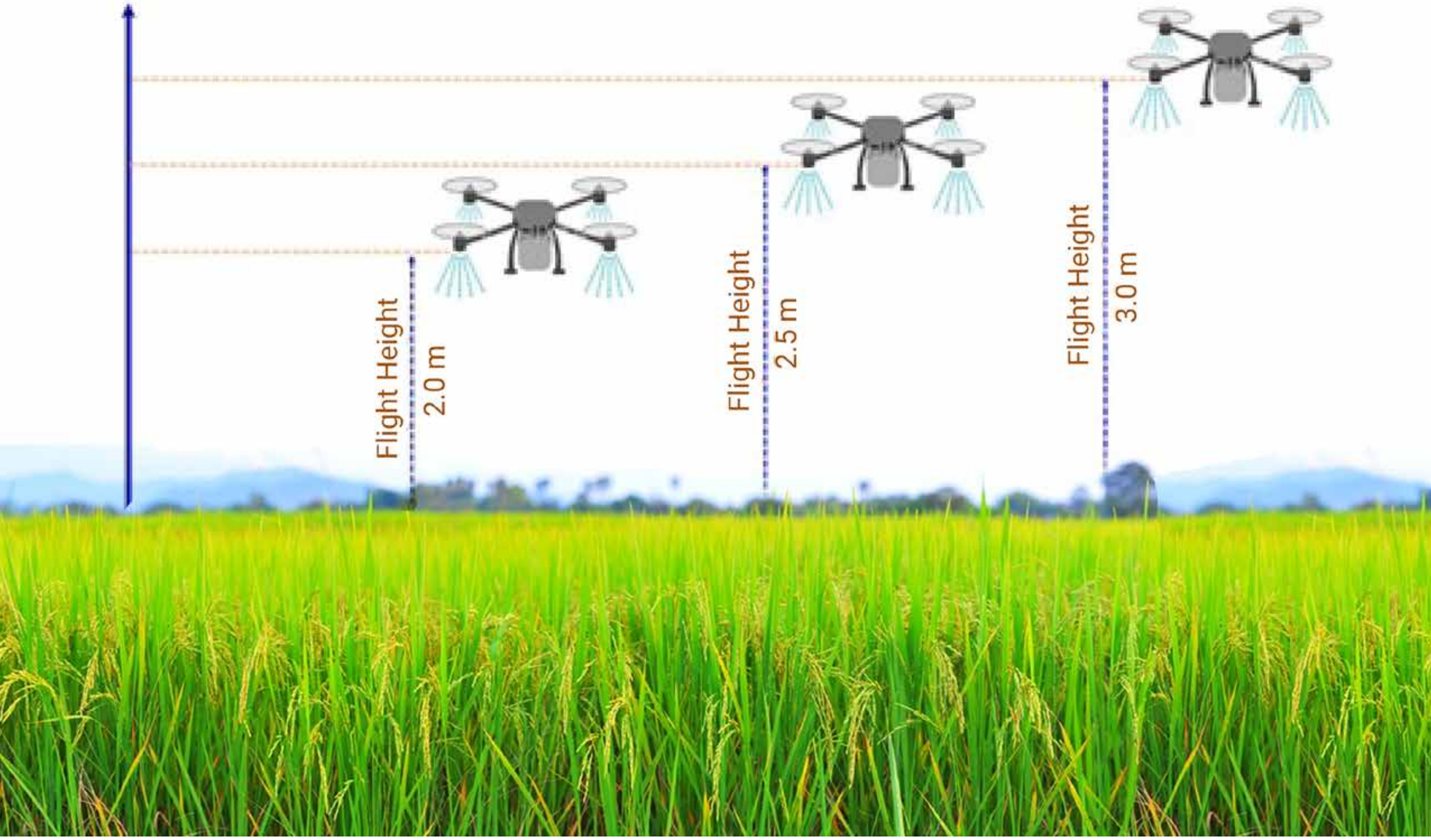


Fig. 6.6 Drone flying test heights

Weather conditions such as wind speed, temperature and relative humidity were monitored and recorded using handheld anemometer (Lutron, AM 4201) and digital hygrometer (HTC, 288 CTH), respectively. During the experimentation period, the wind speed ranged between 1.0 – 2.5 m/s (3.6 to 9 kmph), temperature (30 – 32°C) and relative humidity (90 – 92%). The drone SOP experiments were conducted at flowering stage of the crop, using water as spray suspension and drone was operated at 2.8 m/sec. A minimum of 4 drone flying loops at 3 m spraying width were maintained for each treatment. The WSPs were collected immediately after drone spraying, neatly labelled and placed in aluminium foil covers and stored at room temperature. In laboratory, the WSPs were scanned at a resolution of 600 dpi scanner (Make: Brother DCP-L2514DW) for analysis (Wang *et al.,* 2019). The scanned WSPs were analyzed using mobile based “DepositScan” Analysis software (Zhu *et al.,* 2011) and the droplet parameters such as number of droplets, droplet coverage (%), droplet density (number/cm²) and volume median diameter (VMD 0.5 µm) were estimated. The data was analyzed in two factorial RBD using OPSTAT software package (Sheron *et al.,* 1998).

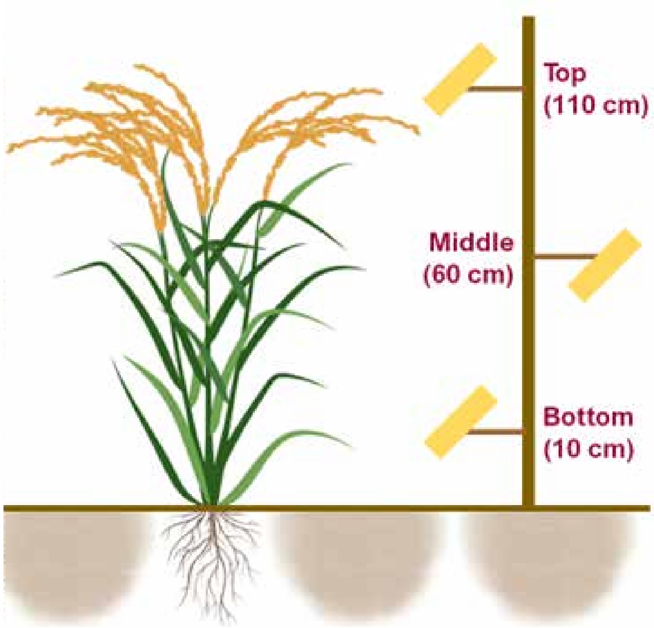


Fig. 6.7 Placement of water sensitive papers at each sampling position within paddy canopy for measuring the droplet parameters

6.1.4 Measurement of Swath Width

The experiment was conducted at Rice Research Centre, Agriculture Research Institute, Rajendranagar during *rabi(Yasangi),* 2020 – 21. Five nozzle types (5) tested in spray coverage experiments were used for measuring the effective spray width using drone at three different heights *viz.,* 2.0, 2.5 m and 3.0 m above crop canopy. Three replications were maintained for each treatment and plots were demarcated for maintaining the buffer zone of 5 meters between the treatments. A plot size of 150 m² was used and three bamboo poles per treatment were placed randomly at different intervals along the drone fly pathway (Fig. 6.8).

Fig. 6.8 Placement of water sensitive papers at each sampling position for measuring spray swath width

The swath width measurements were made at flowering stage of rice crop, using clean water as spray suspension. The water sensitive papers (WSPs) measuring 26×76 mm (M/s. Teejet Technologies, Spraying Systems Co, USA) were placed on bamboo poles of 5 m length at 0.5 m interval from center point (Fig. 6.8) and numbered according to the placement (right to left). The bamboo poles along with WSPs were arranged horizontally 10 cm above the crop canopy and in middle of sampling area across the same flight path at 6 m, 10 m and 14 m distance. The drone was flown through the center of the bamboo stick at 2.8 m/sec flight speed. A minimum of 4-5 drone flying loops at 3 m default spraying width was maintained for each treatment. For each nozzle type, the drone was flown at different heights (flying height – FH) above the crop canopy. After the application was completed, the WSPs were carefully observed for deposition of droplets and the effective spray width was measured using tape (Fig. 6.9). The WSPs were collected carefully, neatly labelled according to the sampling position, placed in aluminium foil and stored at room temperature.

The WSPs were scanned at a resolution of 600 dpi with a scanner (Make: Brother DCP-L2514DW). The scanned WSPs were analyzed using computer based “DepositScan” Analysis software package (Zhu *et al.*, 2011).

Fig. 6.9 Measuring of spray swath width

6.1.5 Results on droplet parameters

The data on the number of drops in different nozzle types *vis a vis* height above the crop canopy indicated that mean no. of drops (n) ranged from 187.2 to 550.0 at a height of 2.0 m above the crop canopy in different nozzle types (Fig. 6.10). It varied from 135.1 to 579.7 and 204.7 to 382.7 drops in different nozzle types at 2.5 and 3.0 above crop canopy, respectively. Among the different nozzle types T2, TXA 8802 VK registered highest no. of drops (504.0) while, lowest number of drops were recorded in T3, TJ 60-025 (176.1). As per overall mean data, optimum range of drops (263.6 to 293.6 drops) were observed only in three nozzle types T1, T4 and T5 (XR 11002 VP, TP 8002 VP and TP 8002 EVS).

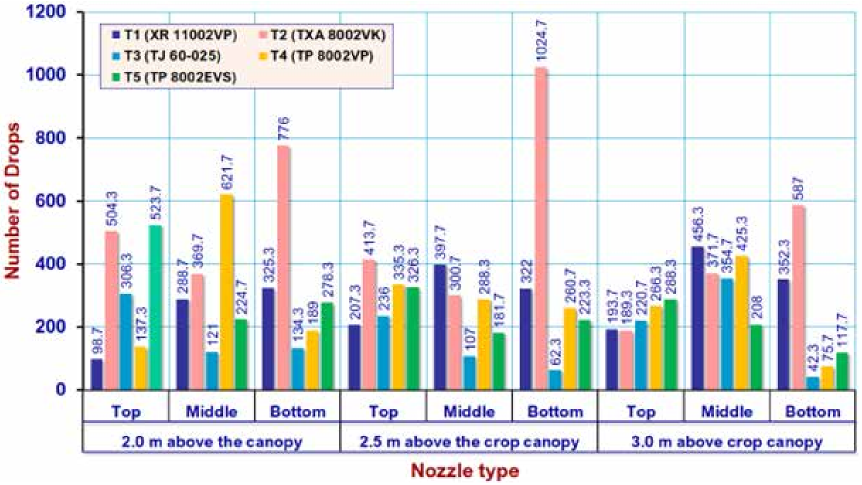


Fig. 6.10 The influence of nozzle type and height of drone spray on number of drops, *kharif* 2020

The perusal of results (Fig. 6.11) revealed that the overall mean volume median diameter across the nozzle types varied from 222.0 to 589.0 µm. At 2.0 m above crop canopy, it varied from 251.0 to 453.0 µm, while it was between 222.0 to 589.0 and 224.7 to 481.0 µm at 2.5 m and 3.0 m height above the crop canopy. Close observation showed that among the different nozzle types evaluated, the volume median diameter was more consistent at different heights in T1, XR 11002 VP (251.0 to 348.0 µm) compared to T2 (222.0 to 364.0 µm), T3 (277.3 to 487.0 µm), T4 (252.0 to 353.3 µm), T5 (310.3 to 589.0 µm). Further, it was more consistent on top, middle and bottom of crop canopy (331.0, 348.0 and 315.0 µm, respectively) at 2.5 m in T1 nozzle type *i.e.* XR 11002VP.

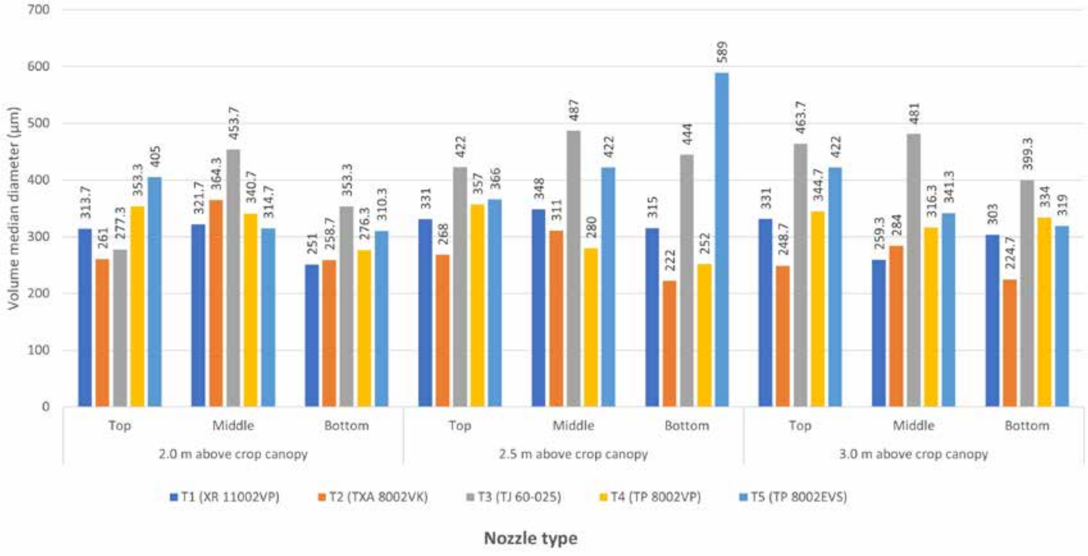


Fig. 6.11 The influence of nozzle type and height of drone spray on volume median diameter, *kharif*,2020

The data indicated that the overall crop coverage ranged from 1.9 to 16.5% among the nozzle types. At 2.0 m above crop canopy, the percent crop coverage varied from 1.9 to 16.2%, while it ranged from 2.2 to 16.5% at 2.5 m and 4.4 to 15.1% at 3 m (Fig. 6.12). As far as crop coverage is concerned T1, XR 11002 VP recorded highest and consistent crop coverage (14.3, 16.5 and 11.5% at top, middle and bottom, respectively) at 2.5 m above crop canopy. The next best nozzle type was T5, TP 8002 EVS which showed consistent coverage at top (14.0, 11.4 and 14.5, respectively at 2.0, 2.5 and 3.0 m), but due to drift inconsistent coverage was noticed at middle and bottom. The coverage (%) in other nozzle types was found to be inconsistent. Irrespective of height of spray above crop canopy, the crop coverage was found to be more consistent with T1, XR 11002VP, when coverage of all the three portions (top, middle and bottom) was considered. While other nozzle types, some were covering the top portion effectively but not reaching to the bottom or *vice versa*.

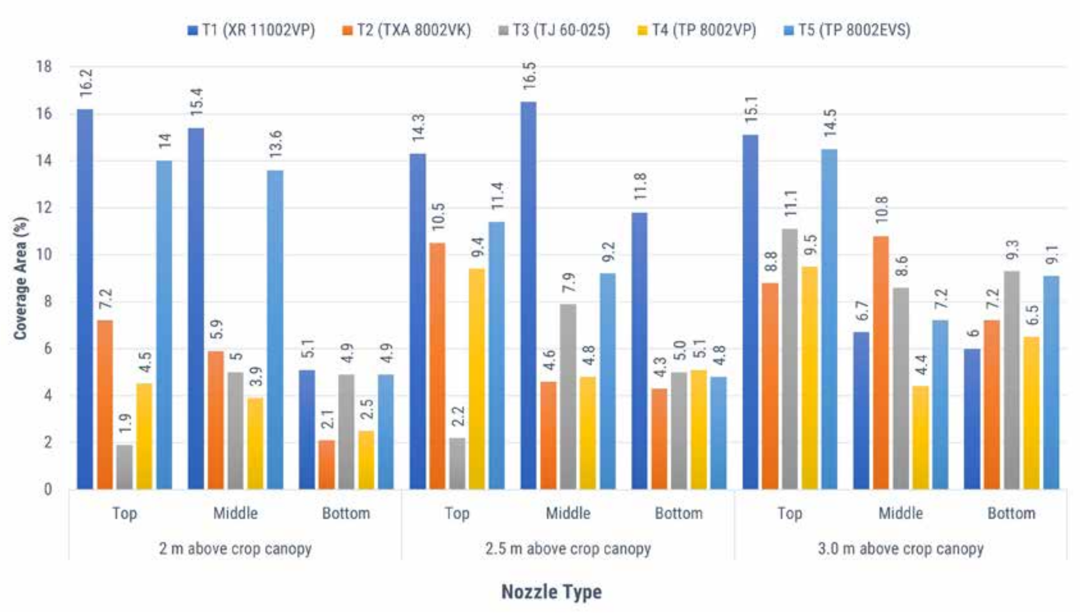


Fig. 6.12 Influence of nozzle type and height of drone spray on crop coverage during *kharif*, 2020

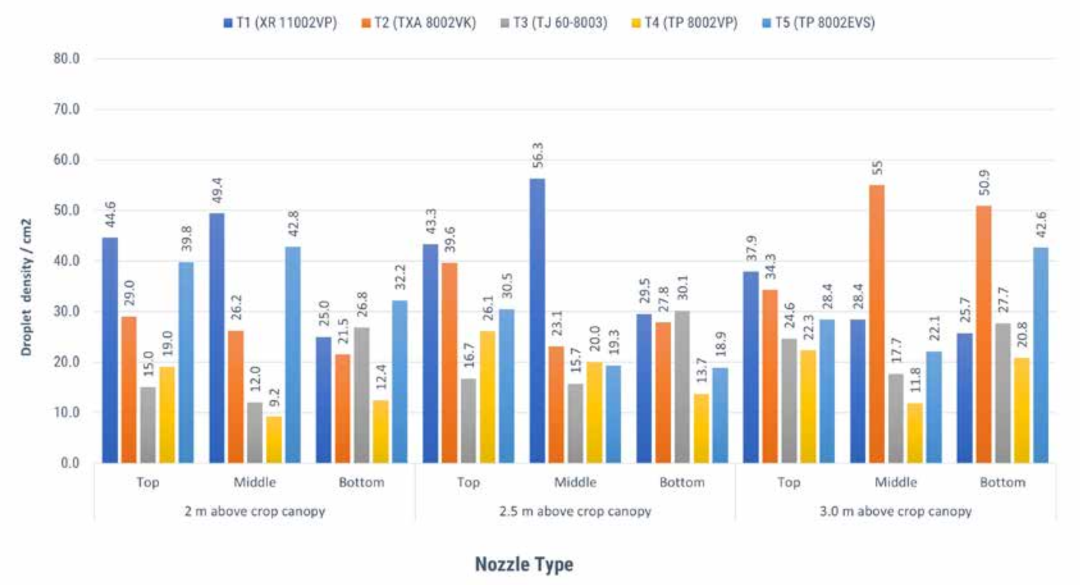


Fig. 6.13 Influence of nozzle type and height of drone spray on droplet density during *kharif,* 2020

The droplet density data on different nozzle types at different spray heights showed that, the overall mean droplet density varied from 9.2 to 56.3/ cm². The nozzle type T1, XR 11002 VP registered droplet density of 44.6, 49.4 and 25.0/cm² at 2.0 meter flying height at top, middle and bottom, respectively (Fig 6.13). Similarly at 2.5 m height it recorded droplet density of 43.3, 56.3 and 29.5/cm² at top, middle and bottom, respectively. While at 3.0m height the droplet densities at top, middle and bottom were 37.9, 28.4 and 25.7/ cm², respectively. The reduced droplet densities at top of the canopy with increase inflying height of drone indicated the possible drift as the height increased. The next best nozzle in terms of droplet density was T2, TXA 8002VK with droplet densities 34.3, 55.0 and 50.9/ cm² at top, middle and bottom, respectively at 3.0m height, while lower drop densities were observed at 2.0 and 2.5 m height. Even though the nozzle type T5, TP 8002 EVS also registered optimum droplet densities of 39.8, 42.8 and 32.2/ cm² at 2.0 m, 30.5, 19.3 and 28.4/ cm² at 2.5 m and 28.4, 22.1 and 42.6/ cm² at 3.0 m drone flying height at top, middle and bottom, respectively the droplet densities decreased as height increased, indicating the possible drift of droplets. The other three nozzle types have also shown inconsistency and lower droplet densities than the above two nozzle types indicating greater drift of spray droplets and were unable to reach the target (Fig 6.13). Perusal of overall data on droplet parameters clearly shows that, nozzle type T1, XR 11002VP performed well at all heights tested with better coverage and droplet density with less drift of spray particles and was reaching all three portions (top, middle and bottom) of the crop and was found optimum at 2.5 m flight height above crop canopy at flight speed of 2.8 m/sec.

Among the nozzles tested, the spray width varied from 4.0 m to 5.0 m depending upon nozzle type and height (Fig. 6.14). The best effective spray width (4.5 to 5.0 m) was obtained with XR 11002VP at 2.0, 2.5 and 3.0 m above the crop canopy. The data revealed that swath width is increasing with increasing spraying height above the crop canopy, irrespective of nozzles tested except with T4 and T5 at 2.5 m above the crop canopy. However, in some nozzle types inconsistencies in spray width were noticed and the drifting of the droplets were observed with increase in drone spraying height. Of the nozzles, XR 11002VP was found to be the best nozzle suitable for drone spraying at 2.5 m above the crop canopy based on the droplet parameter studies as well as spray width.

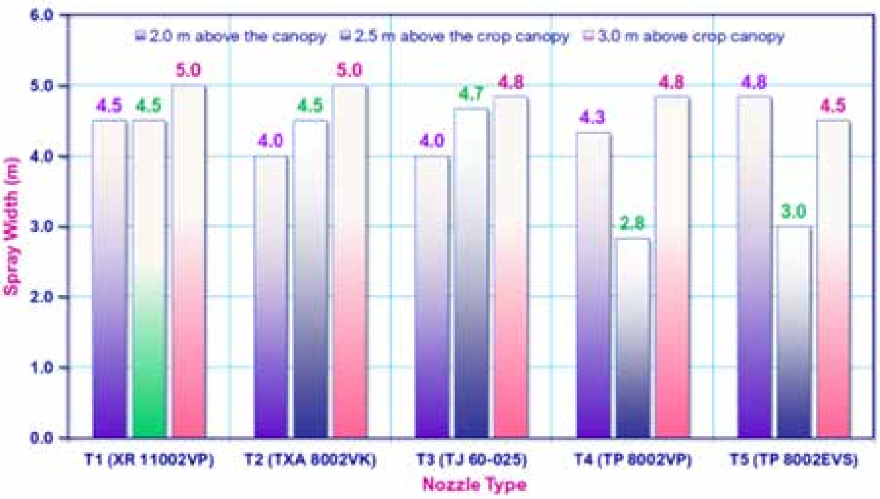


Fig. 6.14. Influence of nozzle type and height of drone spray on swath width during *kharif*, 2020

6.2 Bio-efficacy of pesticides applied through drone against key insect-pests and diseases of rice

6.2.1 Location:

The study was conducted at Kothwalguda village, Shamshabad mandal. Ranga Reddy district, Telangana, India (North Latitude: 17°288463; East Longitude 78°376707; Altitude 542.0 MSL) during *kharif,* 2020 comprising rice variety Telangana Sona (RNR 15048).

6.2.2 Field Layout:

The field was divided into equal size plots for each treatment and replication depending upon the size for conducting the bio-efficacy experiment. A minimum of 15-20 m length plots (Fig 6.15) without having the electrical wires and trees were selected. A minimum plot size of 320 m^2 (20 m x 16 m) per replication per treatment was maintained. The plots were well separated by maintaining buffer zone of five meters between the treatments.

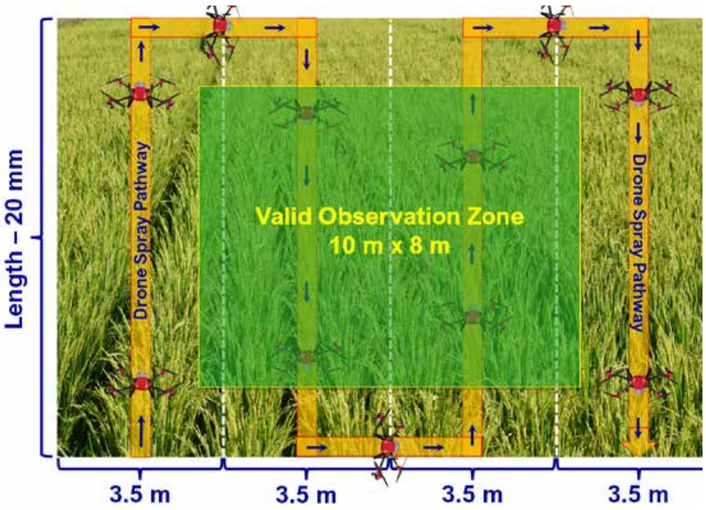


Fig 6.15 Layout of each plot depicting drone path

6.2.3 Drone equipment:

The model of UAV (drone) used in this aerial spraying test was battery motive Agricopter AG365 quadcopter with UNI-UA00132S1EX as per details mentioned in Table 6.2. The best nozzle type identified during SOP studies *viz.,* XR 11002 VP was used for conducting all the bio-efficacy studies. The flying height was maintained at 2.5m above crop canopy and drone was operated at 2.8 m/sec. Before conducting the experiment, the drone pilot has mapped the boundaries of each treatment and replication using drone. The treatment maps along with details were stored in drone remote control. Five meter length buffer zone was maintained to avoid drift, contamination and overlaps in drone flying path per each treatment.

At least 4-5 drone flying paths were allocated in each treatment / replication. Each drone loop covered 3.5 m spraying width at 2.5 m above the crop canopy with drone speed of 2.8 m per second. The discharge rate of the nozzle was adjusted to 60% at flow rate of 2.88 litre/min. Weather data at the time of application was recorded *viz.,* ambient temperature, relative humidity using hygrometer and wind speed using hand-held anemometer. The wind speed ranged between 1.0-1.5 m/s (*i.e.* 3.6 to 5.5 kmph) and temperature (34 to 38^{0}C), and relative humidity (65-70%).

To compare the advantage and limitations of the UAV (drone) with other spraying equipment, we selected a conventional knapsack sprayer for studying control efficacy on rice yellow stem borer, whorl maggot, brown planthopper, false smut, grain discolouration, safety to beneficial fauna and working efficiency tests *etc.*

6.2.4 Knapsack electro battery sprayer

In the bio-efficacy studies, drone aerial spraying was compared with the locally popular manual spraying equipment, knapsack electro battery sprayer (model: AEL00118AHRR) manufactured by ASPEE with a fluid tank capacity of 16 liters (Fig 6.16). The nozzle type was flat fan nozzle. The spraying height of the knapsack sprayer is 0.1 m above the crop canopy, operated at spray pressure of 3.45 bar (50 psi) and flow rate of 3.0 L/min. Under these application conditions, the spray volume was close to 500 L/ha with a field coverage capacity of 2.0 ha/day.

Fig.6.16 Knapsack electro battery sprayer for manual spraying

All working parameters and spray volumes for each sprayer were established taking into account local farmers practices before initiating the experiments. Before experimentation, a preliminary test was performed to calibrate the spraying equipment to ascertain the flow rate of the nozzles, based on which the travelling speed was calculated to obtain the stated application rate and velocity. Each spraying treatment was administered by a well-trained applicator.

6.2.5 Treatment details

The experiment was conducted in randomized block design and comprised off seven treatments *i.e.* 2X, 1.5X, 1X, 0.75X, 0.5X (using drone) and 1X concentration (using battery operated knapsack sprayer) with respective insecticide/fungicide (Table 6.3) with only water spray kept as untreated control and each treatment was replicated four times. The main objective of this trial was to test efficacy of insecticide / fungicide at recommended dose and also assess whether there is any scope for reducing dose while using drone. The experiments were done in two separate blocks ('A' and 'B' blocks).The active ingredient dose g a.i./ha was same in case of drone as well as conventional spray system and considered as 1X dose (dose approved by CIB & RC). Accordingly, 2X, 1.5X, 0.75X and 0.5X dose for drone spraying was calculated (Table 6.4 and 6.5).

Table 6.3. Source of pesticides used in drone experiments

S. No.	Generic Name	Trade Name
1	Chlorantraniliprole 18.5% w/w SC	Coragen
2	Tebuconazole 50 % + Trifloxystrobin 25 % w/w (75 WG)	Nativo
3	Propiconazole 25 EC	Tilt

Table 6.4 Treatment details of insecticide spray (Date of spray: 29.9.2020 – 51 DAT)

Treatment No.	Treatment Details	Formulation (ml)	Chemical per litre of water	Water Volume (l/ha)	Spray Equipment
T1	Chlorantraniliprole 18.5% SC	2X (300 ml)	12.0 ml	25	Drone
T2	Chlorantraniliprole 18.5% SC	1.5X (225 ml)	9.0 ml	25	Drone
T3	Chlorantraniliprole 18.5% SC	1X (150 ml)	6.0 ml	25	Drone
T4	Chlorantraniliprole 18.5% SC	0.75X (112.5 ml)	4.5 ml	25	Drone
T5	Chlorantraniliprole 18.5% SC	0.5X (75 ml)	3.0 ml	25	Drone
T6	Chlorantraniliprole 18.5% SC	1X (150 ml)	0.3 ml	500	Knapsack Sprayer
T7	Untreated Control	Water spray	-	-	-
Note: Chlorantraniliprole 18.5% SC @ 150 ml per ha					

Table 6.5 Treatment details of fungicide spray (Date of spray: 22.10.2020 - 74 DAT)

Treatment No.	Treatment Details	Formulation dose (g/ha)	Chemical per litre of water	Water volume (l/ha)	Equipment for application
T1	Tebuconazole + Trifloxystrobin	2X (400 g)	10 g	40	Drone
T2	Tebuconazole + Trifloxystrobin	1.5X (300 g)	7.5 g	40	Drone
T3	Tebuconazole + Trifloxystrobin	1X (200 g)	5.0 g	40	Drone
T4	Tebuconazole + Trifloxystrobin	0.75X (150 g)	3.75 g	40	Drone
T5	Tebuconazole + Trifloxystrobin	0.5X (100 g)	2.5 g	40	Drone
T6	Tebuconazole + Trifloxystrobin	1X (200 g)	0.4 g	500	Knapsack sprayer
T7	Untreated Control	Water spray	-	-	-
Note: Tebuconazole 50 % + Trifloxystrobin 25 % w/ w (75 WG) @ 200 g per ha					

6.2.5.1 Spraying Schedule:

The first spray (insecticide) was done at the time of initial observation of insect-pests at P.I to booting (29.9.2020 at 51 DAT). In order to avoid yield losses due to diseases in farmers field, fungicide was sprayed as 2nd spray in addition to the insecticide using drone at flowering stage of the crop (22.10.2020 at 74 DAT). The spray fluid varied from 25 litres/ha during 1st spray to 40 litres/ha during 2nd spray depending upon crop stage (Fig 6.17).

6.2.5.2 Data recording:

The data was recorded 7 and 14 days after each spray event from 10 randomly selected hills per treatment in each replication.

6.2.5.2.1 Yellow stem borer:

Total number of tillers, panicle bearing tillers, dead hearts and white ears were recorded on 10 randomly selected hills in each treatment and replication. From these data means and percent incidence was calculated based on damage symptoms (dead hearts and white ears) as follows.

6.2.5.2.2 Beneficial Fauna:

The data on beneficial fauna (coccinellids, mirid bugs and spiders) was also recorded 7 and 14 days after each insecticide spray event.

$$\%\ \text{Dead heart incidence} = \frac{\text{Number of Dead hearts}}{\text{Total number of tillers}}\ \text{x}100$$

$$\%\ \text{White ear incidence} = \text{x}\frac{\text{Number of White ears}}{\text{Total number of Panicle bearing tillers}}\quad 100$$

Fig. 6.17. Visit of drone validation team to rice experimental fields at Kothwalguda (V), Shamshabad (M), Rangareddy(Dt) on 24-9-2020

6.2.5.2.3 Disease data:

The data on false smut damaged panicles and grain discolouration were recorded from 10 randomly selected hills in each replication. The data included total number of panicles, number of false smut damaged panicles, total number of grains per panicle and number of discoloured grains per panicle. The percent false smut damage and percent grain discolouration were computed as follows.

$$\%\ \text{False smut incidence} = \frac{\text{Number of damaged panicles}}{\text{Total number of panicles}} \text{x100}$$

$$\%\ \text{Grain discolouration} = \frac{\text{Number of discoloured grains}}{\text{Total number of grains}} \text{x100}$$

Before spraying of fungicide using drone, pre-count observations on incidence of diseases were recorded. Post application observations in each treatment and replication were recorded at 7 and 14 days after each spray event

6.2.5.2.4 Grain yield:

The grain yield data was recorded from five m² area per each treatment and replication at maturity of the crop and the data was converted to kg/ha. All the data was subjected to suitable transformation and statistically analyzed.

6.2.6 Results

6.2.6.1 Effect of Chlorantraniliprole18.5%SC at variable rates using drone on rice yellow stem borer in *kharif*, 2020

Perusal of data showed that the dead heart incidence one week after spraying varied from 3.96 to 6.15% across the treatments, but did not differ significantly. However, the treatment differences were more evident two weeks after spraying, wherein dead heart incidence ranged from 2.72 to 10.58% between the treatments (Table 6.6). The drone spray treatments, T1 at 2.0X dose, T2 at 1.5X dose and T3 at 1.0X dose registered significantly lowest per cent dead hearts (2.72, 2.85 and 3.20, respectively) followed by T6, knapsack spray @ 1X dose (4.00% dead hearts). The performance of T1, T2, T3 was significantly superior over untreated control (10.68% DH) and T4 and T5 treatments registered significantly higher dead heart incidence (5.40 and 5.98%, respectively). All the drone treatments T1 to T4 (2X, 1.5X, 0.75X and 0.5X) and T6, knapsack spray @ 1X dose registered significantly lower white ear incidence compared to untreated control. Further,significantly higher grain yield (7000 kg /ha) accrued in drone 1X dose (T3) than T7, untreated control (4837.5 /ha)

Table 6.6.Effect of insecticide spray by drone on yellow stem borer infestation and grain yield of rice in *kharif*, 2020

Treatment	Formulation dose (ml/ha)	Dead hearts (%) at 7 DAS	Dead hearts (%) at 14 DAS	White ears (%) WE 1	White ears (%) WE2	Grain Yield (kg/ha)
T1 (Drone)	2X (300 ml)	4.68 (12.41)	2.72^{a} (9.31)	0.00^{a} (0.00)	0.32^{b} (3.23)	6887.5^{a}
T2 (Drone)	1.5X (225 ml)	4.48 (12.12)	2.85^{a} (9.61)	0.00^{a} (0.00)	0.00^{a} (0.00)	5937.5^{b}
T3 (Drone)	1X (150 ml)	5.28 (13.25)	3.20^{a} (10.29)	0.61^{a} (4.46)	0.47^{b} (3.94)	7000.0^{a}
T4 (Drone)	0.75X (112.5 ml)	6.01 (14.13)	5.40^{b} (13.40)	0.00^{a} (0.00)	0.00^{a} (0.00)	6112.5^{a}
T5 (Drone)	0.5X (75 ml)	7.30 (15.43)	5.98^{b} (14.12)	0.00^{a} (0.00)	0.49^{b} (3.97)	6275.0^{a}
T6 (Knapsack)	1X (150 ml)	3.96 (11.37)	4.00^{ab} (11.47)	0.58^{b} (4.33)	0.57^{b} (4.30)	5787.5^{bc}
T7 (Untreated Control)	Water spray	6.15 (14.34)	10.58^{c} (18.92)	4.25^{c} (11.85)	13.13^{c} (21.13)	4837.5^{c}
CD		NS	2.16	0.87	1.54	967.3
SE(m)±		-	0.72	0.29	0.59	323.1
CV (%)		-	11.59	19.62	19.64	10.56

**Figures in parentheses are arc sine values*

Table 6.7. Effect of insecticide spray by drone on beneficial fauna in rice fields during *kharif*, 2020

Treatment No.	Formulation dose/ha	Coccinellids at 7 DAS	Coccinellids at 14 DAS	Spiders at 7 DAS	Spiders at 14 DAS	Mirid bugs at 7 DAS	Mirid bugs at 14 DAS
T1 (Drone)	2X (300 ml)	0.00 (1.00)	0.00 (1.00)	2.50 b (1.85)	1.00 (1.35)	0.00 (1.00)	2.25 b (1.77)
T2 (Drone)	1.5X (225 ml)	0.00 (1.00)	0.00 (1.00)	1.75ab (1.64)	0.25 (1.10)	0.25 (1.10)	4.00c (2.33)
T3 (Drone)	1X (150 ml)	0.25 (1.10)	0.00 (1.00)	2.50 b (1.86)	0.50 (1.21)	0.25 (1.10)	2.75 b (1.93)
T4 (Drone)	0.75X (112.5 ml)	0.25 (1.10)	0.00 (1.00)	0.50 a (1.21)	0.25 (1.10)	1.00 (1.39)	0.00 a (1.00)
T5 (Drone)	0.5X (75 ml)	0.25 (1.10)	0.00 (1.00)	0.75a (1.28)	0.25 (1.10)	0.50 (1.21)	0.00 a (1.00)
T6 (Knapsack)	1X (150 ml)	0.50 (1.21)	0.00 (1.00)	1.50 ab 1.56)	0.25 (1.10)	0.50 (1.18)	0.00 a (1.00)
T7 (Untreated Control)	Water spray	0.00 (1.00)	0.00 (1.00)	2.25b (1.76)	0.25 (1.10)	0.50 (1.21)	0.00 a (1.00)
CD		NS	NS	0.47	NS	NS	0.27
SE(m) ±		-	-	0.16	-	-	0.09
CV (%)		-	-	19.65	-	-	12.67

** Figures in parentheses are square root values; DAS = Days after spray*

6.2.6.2
Effect of Chlorantraniliprole 18.5%SC at variable rates using drone on beneficial fauna in rice, *kharif*,2020

The studies on the influence of drone-based spraying of Chlorantraniliprole18.5% SC at different doses on beneficial fauna of rice indicated that the treatment differences were non-significant with regard to coccinellids both at 7th day and 14th day after spray, spiders at 14th day after spray and mirid bugs after 7th day after spray (Table 6.7). However, the spider populations were significantly low in T4 (0.75X) and T5 (0.5X) wherein only 0.50 to 0.75 spiders/10hills were recorded followed by T2 (1.5X) and T6, knapsack spray at 1X dose (1.75 and 1.50 spiders /10 hills, respectively). The spider populations did not differ among T1(2X), T3(1X) and untreated control. The mirid bug populations were found to be low at lower doses of drone spray treatments *viz.*, T4 (0.75X) and T5 (0.5X), knapsack spray (T6) and untreated control (T7) when compared to drone spray treatments, T2 (1.5X), T3 (1X) and T1 (2X).

6.2.6.3
Effect of Tebuconazole 50% + Trifloxystrobin 25%WG (75WG) at variable rates using drone on rice diseases in *kharif,* 2020

False smut infection varied markedly among drone spray, knapsack spray and untreated control. Treatment T2 (drone spray at 1.5X) at 7 days after spray and knapsack spray (T6) at 14 days after spray exhibited better control of false smut and had lowest incidence of 1.95% and 1.92%, respectively. Whereas, significantly highest false smut incidence was noticed in T4 – drone spray at 0.75X treatment both at 7 (4.99%) and 14 days (6.83%) after spray. Effect of other treatments on false smut control varied with time (7 and 14 DAS), spray type (drone and knapsack) and fungicide dose (0.5X to 2X) (Table 6.8).

The per cent grain discolouration among different treatments varied from 6.30 to 10.20% at 7 days after spray and from 6.47 to 10.95% at 14 days of spray.Among various treatments,T3 (drone spray @1X dose) at 7 days after spray and T6 (knapsack spray @1X dose) at 14 days after spray registered lowest grain discolouration of 6.30 and 6.71%, respectively, which were on par with T2 and T5 with 7.92 and 8.51% GD, respectively (Table 14). Both T3 and T6 treatments were significantly superior over all the other treatments. Similarly, 14 days after spray also treatments T6 (5.58% GD) registered significantly lower grain discolouration followed by T3 and T4 (1X and 1.5X dose drone sprays, respectively).

Table 6.8. Effect of fungicide (Tebuconazole + Trifloxystrobin) spray at variable rates by drone on rice diseases in *kharif,* 2020

Treatment No.	Formulation dose/ha	False Smut (%) damage at 7 DAS	False Smut (%) damage at 14 DAS	Grain discoouration (%) at 7 DAS	Grain discolouration (%) at 14 DAS
T1 (Drone)	2X (400 g)	2.57^{ab} (9.13)	3.78 (11.08)^{b}	10.20 (18.57)^{b}	8.02 (16.41)^{b}
T2 (Drone)	1.5X (300 g)	1.95^{a} (7.90)	4.49 (12.18)^{b}	7.92 (16.24)^{ab}	6.66 (14.93)^{ab}
T3 (Drone)	1X (200 g)	3.65^{b} (10.91)	4.95 (12.69)^{b}	6.30 (14.50)^{a}	6.47 (14.72)^{ab}
T4 (Drone)	0.75X (150 g)	4.99^{b} (12.81)	6.83 (15.11)^{c}	9.10 (17.53)^{b}	9.71 (18.13)^{b}
T5 (Drone)	0.5X (100 g)	4.07 (11.59)^{b}	2.64 (9.24)^{ab}	8.51 (16.90)^{ab}	7.68 (16.07)^{b}
T6 (Knapsack)	1X (200 g)	2.81 (9.63)^{ab}	1.92 (7.91)^{a}	6.71 (14.72)^{a}	5.58 (13.63)^{a}
T7 (Untreated Control)	Water spray	4.58 (12.34)^{b}	3.96 (11.47)^{b}	10.10 (18.48)^{b}	10.95 (19.28)^{c}
CD		2.10	2.45	2.88	1.55
SE(m)±		0.70	0.82	0.96	0.52
CV(%)		13.23	14.36	11.51	6.39

** Figures in parentheses are arc-sine values*

6.2.6.4 Effect of insecticide and fungicide spray at variable rates using drones in *kharif*, 2020 on grain yield and Incremental Cost Benefit Ratio

Markedly higher grain yield was recorded in T3 (Table 6.6) drone spray at 1X dose (7000 kg/ha) over other treatments. Incremental grain yield over untreated control varied from 9.5 to 21.6 q/ha. Whereas, the increase in grain yield by drone spray at recommended rate of 1X (T3) amounted to 10.2%, 17.8%, 14.5%, 11.4%, 20.8% and 44.6% over T1, T2, T4, T5, T6 and T7 treatments, respectively. On the other hand applying either lower insecticide dose of 0.75X (T4) and 0.5X (T5) or higher insecticide dose of 2X (T1) and 1.5X (T2) by drone spray did not prove to be advantageous over recommended dose of 1X (T3). Conventional knapsack spray at 1X (T6) was found to be inferior when compared to drone spray treatments (T1 to T5). Expectedly untreated control had lowest yield 48.4 q/ha.

Insecticide spray using drones significantly increased the incremental returns from Rs. 23817/ha to Rs. 40396/ha. Conventional knapsack spray registered Rs. 17746/ha incremental benefit over untreated control. Overall the incremental benefit cost ratio was higher and varied from 1:2.80 to 1:7.03 suggesting an improved efficiency and cost savings by drone spray when compared with conventional knapsack spray (1:3.09) (Table 6.9).

Table 6.9. Incremental cost benefit ratio of insecticide/fungicide spraying with drones (A-block)

Treatment No.	Grain yield (q/ha)	Incremental yield over control (q/ha)	Incremental returns over control (Rs/ha)	Incremental cost of cultivation (Rs/ha)	ICBR
T1 (2X)	68.9	20.5	38294	10500	1:3.65
T2 (1.5X)	59.4	11.0	20548	7333	1:2.80
T3 (1X)	70.0	21.6	40396	5750	1:7.03
T4 (0.75X)	61.1	12.8	23817	4562	1:5.22
T5 (0.5X)	62.8	14.4	26853	3375	1:7.96
T6 (Knapsack1X)	57.9	9.5	17746	5750	1:3.09
T7 (Untreated Control)	48.4	0.0	-	-	-

ICBR - Incremental Cost Benefit Ratio; Market price of Paddy - Rs.1868/q; Cost of insecticide Chlorantraniliprole18.5% (150ml) - Rs. 2350/ha, Tebuconazole50%+Trifloxystrobin25%WG (75WG) (200g) - Rs. 2400/ha; Spraying cost (ha); Battery operated knapsack sprayer: Rs.1000 & Drone: Rs.1000/-

BLOCK B:

Another experiment was conducted in during *kharif*, 2020 using RNR 15048 rice variety planted on 14th August 2020 following all protocols and standard procedures as mentioned above. The details of insecticides and fungicides used are provided in Table 6.10 to 6.12.

Table 6.10 Treatment details of fungicide spray (Date of spray: 29.9.2020 – 48 DAT)

Trt. No.	Treatment	Formulation (ml)	Chemical volume per litre of water	Water volume (l/ha)	Equipment for application
T1	Tebuconazole + Trifloxystrobin	2X (400 g)	16 g	25	Drone
T2	Tebuconazole + Trifloxystrobin	1.5X (300 g)	12 g	25	Drone
T3	Tebuconazole + Trifloxystrobin	1X (200 g)	8 g	25	Drone
T4	Tebuconazole + Trifloxystrobin	0.75X (150 g)	6 g	25	Drone
T5	Tebuconazole + Trifloxystrobin	0.5X (100 g)	4 g	25	Drone
T6	Tebuconazole + Trifloxystrobin	1X (200 g)	0.4 g	500	Knapsack sprayer
T7	UTC	Water spray	-	-	-

** Tebuconazole 50% + Trifloxystrobin 25% w/w (75WG) @ 200 g /ha*

Table 6.11 Treatment details of insecticide spray (Date of spray: 22.10.2020 – 71 DAT)

Treatment No.	Treatment Details	Formulation (ml)	Chemical volume per litre of water	Water volume (l/ha)	Equipment for application
T1	Chlorantraniliprole	2X (300 ml)	7.5 ml	40	Drone
T2	Chlorantraniliprole	1.5X (225 ml)	5.6 ml	40	Drone
T3	Chlorantraniliprole	1X (150 ml)	3.75 ml	40	Drone
T4	Chlorantraniliprole	0.75X (112.5 ml)	2.8 ml	40	Drone
T5	Chlorantraniliprole	0.5X (75 ml)	1.9 ml	40	Drone
T6	Chlorantraniliprole	1X (150 ml)	0.3 ml	500	Knapsack sprayer
T7	UTC	Water spray	-	-	-

** Chlorantraniliprole 18.5% SC @ 150 ml /ha*

Table 6.12 Treatment details of Fungicide spraying (Date of spray: 30.10.2020-79 DAT)

Treatment No.	Treatment Details	Formulation (ml)	Chemical volume per litre of water	Water volume (l/ha)	Equipment for application
T1	Propiconazole	2X (1000 ml)	25 ml	40	Drone
T2	Propiconazole	1.5X (750 ml)	18.75 ml	40	Drone
T3	Propiconazole	1X (500 ml)	12.5 ml	40	Drone
T4	Propiconazole	0.75X (375 ml)	9.375 ml	40	Drone
T5	Propiconazole	0.5X (250 ml)	6.25 ml	40	Drone
T6	Propiconazole	1X (500 ml)	1.0 ml	500	Knapsack sprayer
T7	UTC	-	-	-	-

** Propiconazole 25% EC @ 500 ml /ha*

6.2.6.5

Effect of drone-based spraying of Chlorantraniliprole18.5%SC at different doses on rice yellow stem borer and beneficial fauna in rice, *kharif,* 2020

Another trial was conducted at different block (B) to assess the impact of drone spraying on rice yellow stem borer. The data showed that both knapsack spray and drone spray at 1X dose exhibited excellent control against stem borer (2.75 to 3.79% WE) compared to untreated control (9.64% WE) during first observation (Table 6.13). Similar observations were made during second observation also, where in T6 and T3 treatments registered significantly lower incidence of YSB with 3.36 and 4.45% WE as against untreated control (7.59% WE). Significantly higher mirid bugs were recorded in drone spraying treatments 0.75X to 1.5X with 9.75 to 9.00 / 10 hills compared to only 1.50 mirid bugs/10 hills in 1x Knapsack and untreated control.

6.2.6.6

Effect of drone-based spraying of Propiconazole on rice diseases, *kharif,* 2020

The data on impact of propiconazole spray at different doses using drones revealed that, lowest false smut infection was observed with treatment T2 *i.e.* drone spray at 1.5X (5.38%) which was onpar with T3 (1X),T1(2X) and T4 (0.75X) and all these treatments exercised superior control over T5, T6 and untreated control (Table 6.14). But after 14 days of spray, greater persistence was observed at higher doses *viz.,* 1.5 and 2X doses (4.29 and 5.07%, respectively). Further, the percent grain discolouration varied from 30.75 to 47.00 across the treatments, with all the drone treatments offered better control with lower grain discolouration over T6, knapsack spray and untreated control.

Table 6.13. Effect of insecticide spraying with drones on rice yellow stem borer and mirid bugs, *kharif,* 2020

Treatments	Formulation /ha	%WE 1*	%WE 2*	MB/10 hills (7 DAS)#	Grain yield (kg/ha)
T1 (Drone)	2X (300 ml)	4.47^{b} (12.02)	5.07^{b} (12.95)	5.25^{b} (2.46)	5900.00^{b}
T2 (Drone)	1.5X (225 ml)	5.06^{b} (12.96)	7.07^{c} (15.39)	9.50^{bc} (3.19)	5925.00^{abc}
T3 (Drone)	1X (150 ml)	3.79^{a} (11.16)	4.45^{ab} (12.16)	9.00^{c} (3.48)	6375.00^{a}
T4 (Drone)	0.75X (112.5 ml)	4.80^{b} (12.56)	4.88^{b} (12.73)	9.75b^{c} (3.28)	5725.00^{abc}
T5 (Drone)	0.5X (75 ml)	4.45^{b} (12.17)	7.02^{c} (15.29)	1.00^{a} (1.35)	5112.50^{b}
T6 (Knapsack)	1X (150 ml)	2.75^{a} (9.34)	3.36^{a} (10.55)	1.50 ^{a} (1.49)	5337.50^{b}
T7 (UTC)	Water spray	9.64^{c} (18.07)	7.59^{c} (15.93)	1.50^{a} (1.55)	4687.75^{b}
CD		2.56	1.88	0.76	906.2
SE(m) ±		0.85	0.63	0.25	302.7
CV%		13.54	9.25	21.02	10.85

** Figures in parentheses are arc sine values*

 # Figures in parentheses are square root values; DAS = Days after spray

6.2.6.7

Effect of drone-based insecticide and fungicide spraying on rice grain yield, *kharif,* 2020 and Incremental Cost Benefit Ratio

Significantly higher grain yield was recorded in T3, drone spray at 1X dose (6375 kg/ha) on par with drone sprays at 1.5X, 2X and 0.75X (Table 6.13). But drone spray at 0.5X and knapsack spray @ 1X and untreated control realized significantly lower grain yield (5337.5 to 4687.75 kg/ha). In block B during *kharif,* 2020, the drone spray at 1X dose registered higher incremental benefit cost ratio (7.00) as against knapsack spray at 1X (2.70) and was found most cost effective than all other drone spray doses (Table 6.15).

Table 6.14. Effect of spraying of propiconazole with drones on rice diseases *kharif,* 2020

Treatments	Formulation /ha	%FS (7 DAS)*	%FS (14 DAS)*	%GD (At Harvesting)*
T1 (Drone)	2X (1000 ml)	7.05^{a} (15.23)	5.07^{a} (12.67)	34.25^{ab} (35.77)
T2 (Drone)	1.5X (750 ml)	5.38^{a} (13.35)	4.29^{a} (11.58)	32.75^{ab} (34.84)
T3 (Drone)	1X (500 ml)	6.75^{a} (14.82)	7.14^{b} (15.39)	31.50^{ab} (34.07)
T4 (Drone)	0.75X (375 ml)	7.44^{a} (15.82)	6.71^{ab} (15.00)	30.75^{a} (33.66)
T5 (Drone)	0.5X (250 ml)	11.41^{b} (19.50)	6.94^{ab} (15.22)	35.50^{ab} (36.54)
T6 (Knapsack)	1X (500 ml)	10.75^{b} (19.02)	6.35^{ab} (14.45)	37.75^{b} (37.89)
T7 (UTC)	Water Spray	9.20^{b} (17.65)	11.84^{c} (19.87)	47.00^{c} (43.26)
CD		3.68	3.67	4.10
SE(m) ±		1.23	1.21	1.37
CV(%)		14.91	16.19	7.49

Treatment: Propiconazole 25 EC @ 500 ml/ha Date of Treatment: 30.10.2020; DAS: Days After Spray
**Figures in parentheses are arc sine values   #Figures in parentheses are square root values*

Table 6.15. Incremental cost benefit ratio of bio-efficacy of fungicide spraying with drones during *kharif*, 2020

Treatments	Grain yield (q/ha)	Incremental yield over control (q/ha)	Inremental returns over control (Rs/ha)	Incremental cost of cultivation (Rs/ha)	ICBR
T1 (Drone 2X)	59.0	12.1	22645	8000	1:2.83
T2 (Drone 1.5X)	59.3	12.4	23112	5670	1:;4.08
T3 (Drone 1X)	63.8	16.9	31518	4500	1:7.00
T4 (Drone 0.75X)	57.3	10.4	19376	3625	1:5.35
T5 (Drone 0.50X)	51.1	4.2	7934	2750	1:2.89
T6 (Knapsack 1X)	53.4	6.5	12137	4500	1:2.70
T7 (UTC)	46.9	0.0	-	-	-

ICBR: Incremental Cost Benefit Ratio. Market price of Paddy: Rs.1868/quintal.
Chlorantraniliprole18.5%w/w(150 ml)@ Rs. 2350/-ha;
Tebuconazole 50%+Trifloxystrobin 25% WG (75 WG) (200 g) @ Rs. 2400 per ha; Propiconazole (500 ml)@ Rs. 1100 perha
Spraying cost (ha) : Battery operated knapsack sprayer: Rs. 1000 & Drone: Rs.1000/-

6.3 Bio-efficacy of Chlorantraniliprole applied through drone against rice stem borer and grain yield *rabi,* 2020-21

6.3.1 Location

Another study was conducted at SRTC plots, ARI, Rajendranagar (Located adjacent to rice research centre) during *rabi,* 2020-21 following all standard procedures as mentioned earlier, comprising rice variety RNR 15048 in 1 ha area, planted on 24th January 2021 with seven treatments in randomized block design, replicated four times. The best nozzle type identified during SOP studies *viz.,* XR 11002 VP was used for conducting bio-efficacy studies maintaining drone spraying height of 2.5 m and flying speed of 2.8 m/sec.

6.3.2 Spraying Schedule:

Only one spray of insecticide chlorantraniliprole was done at the time of initial observation of insect-pests (PI to booting stage). The fungicide spraying was not taken up due to very low or < ETL incidence of diseases during *rabi,* 2020-21.

6.3.3 Results:

The effect of drone spraying of Chlorantraniliprole 18.5SC on stem borer was assessed at different doses during *rabi,* 2020-21. During *rabi,* the incidence of dead hearts was meager, while the white ear incidence (WE) ranged from 1.65 to 6.39% across the treatments (Table 6.16). Among the treatments, significantly lowest white ears were noticed in T3, drone spray@1X (1.65% WE) followed by T6, knapsack @ 1X (2.03% WE) and T1, drone spray @ 2X (2.29% WE) which were significantly superior over T5, drone spray @0.5X (4.55% WE) T4, drone spray @0.75X (4.91% WE) and Untreated control (6.39% WE).

The grain yield was significantly higher in T6 (Table 6.12), knapsack spray @ 1X (6112.50 kg/ha) followed by T1, drone spray @ 2X (5687.5 kg/ha) and T3, drone spray @ 1X (5575.5 kg/ha). Significantly lowest grain yield was recorded in untreated control and T4, drone spray @ 0.75X (4812.5 kg/ha) which were on par with T5, drone spray @ 0.5X (5200 kg/ha). The Incremental Cost Benefit Ratio during *rabi,* 2020-21 (Table 6.17) revealed that, knapsack spray at 1X dose realized higher ICBR (7.25) followed by drone spray at 1X dose (4.25), while all other drone spray doses realized less cost benefit.

Table 6.16. Effect of insecticide spraying with drones on incidence yellow stem borer and grain yield, *rabi*, 2020-21

Treatments	Formulation/ha	%WE (Pre-harvest)	Grain Yield (kg/ha)
T1 (Drone)	2X (300 ml)	2.29^{ab} (8.47)	5687.50^{ab}
T2 (Drone)	1.5X (225 ml)	2.87^{b} (9.74)	5037.50^{b}
T3 (Drone)	1X (150 ml)	1.65^{a} (7.30)	5575.00^{ab}
T4 (Drone)	0.75X (112.5 ml)	4.91^{c} (12.79)	4812.50^{b}
T5 (Drone)	0.5X (75 ml)	4.55^{c} (12.20)	5200.00^{b}
T6 (Knapsack)	1X (150 ml)	2.03^{ab} (8.10)	6112.50^{a}
T7 (UTC)	Water spray	6.39^{c} (14.58)	4812.50^{b}
CD		2.40	861.73
SE(m)		1.13	407.01
CV		5.34	10.82

Treatment: Insecticide (Chlorantraniliprole18.5%w/w), Date of Treatment:10.4.2021
**Figures in parentheses are arc sine values*

In the experiment conducted in SRTC plots, the drone spray at 1X dose with knapsack spray registered higher incremental benefit cost ratio (7.25) as against drone spray at 1X (4.25). It was found to be most cost effective than all other drone spray doses (Table 6.17).

Table 6.17. Incremental cost benefit ratio of bio-efficacy of cholrantraniliprole spraying with drones during *rabi*, 2020-21

Treatments	Grain yield (q/ha)	Incremental yield over control (q/ha)	Incremental returns over control (Rs/ ha)	Incremental cost of cultivation (Rs/ha)	ICBR
T1 (2X)	56.9	8.8	16345	5700	1:2.87
T2 (1.5X)	50.4	2.3	4203	4133	1:1.02
T3 (1X)	55.8	7.6	14244	3350	1:4.25
T4 (0.75X)	48.1	0.0	0	2763	1:0.00
T5 (0.5X)	52.0	3.9	7239	2175	1:3.33
T6 (Knapsack1X)	61.1	13.0	24284	3350	1:7.25
T7 (Untreated control)	48.1	-	-	-	-

ICBR: Incremental Cost Benefit Ratio. Market price of Paddy: Rs. 1868/quintal.
Chlorantraniliprole18.5% w/w (150 ml) @ Rs. 2350/-per ha;
Spraying cost (ha): Battery operated knapsack sprayer: Rs. 1000 & Drone: Rs. 1000/-

6.4 Bio-efficacy of pesticides along with adjuvants applied through drone against rice YSB

Adjuvants are substances used with a pesticide or herbicide to enhance performance, which may be added by the applicator to the spray mix just prior to treatment. Adjuvants include surfactants, compatibility agents, anti-foaming agents and spray colorants (dyes) and drift control agents. Currently, tank-mix spray adjuvants are usually added into pesticide solutions to reduce spray drift and facilitate droplet deposition and control efficacy. The currently used tank-mix adjuvants are all derived from conventional ground sprays, and their mechanisms of action in aerial applications are still unclear. In order to study the control efficacy of some of the adjuvants in aerial sprays, the performances of various types of tank-mix adjuvants were studied. Wang *et al.,* 2022 reported that adding adjuvants to the spray solution can significantly improve the control efficacy of pesticides on wheat aphids and rust and can also prolong the duration of pesticides. Usually these adjuvants included methylated seed oils, organosilicons, mixture of fatty acid esters *etc.,* Therefore, some of the adjuvants were used along with Chlorantraniliprole 18.5%SC in drone based aerial spraying and control efficacy was evaluated.

6.4.1 Experimental details:

The efficacy evaluation of Chlorantraniliprole 18.5%SC @ 150 ml/ha (1X dose) along with adjuvants (as detailed below) applied through drone against whorl maggot and yellow stem borer was studied during *rabi,* 2020-21 at SRTC plots, ARI, Rajendranagar. The variety selected for conducting the adjuvant experiment is "Kunaram Sannalu (KNM 118)". The experiment was laid out in RBD with 6 treatments and 4 replications for each treatment. The row to row spacing is 15 cm and plant to plant is 15 cm. The nursery was sown on 17.12.2020 and planted on 21.01.2021.

S. No.	Generic Name	Trade Name
	ADJUVANTS	
1.	Trisiloxane Ethoxylate	Silvet Gold
2.	-	Wetcit
3.	-	Agri-82
4.	-	Dhanuvit

6.4.2 Spraying Schedule:

The 1X dose of insecticide along with different adjuvants (Table 6.18) were sprayed at initial observation of insect-pests (PI to booting stage). A total of 4 adjuvants (Silwet, Wetcit, Agri-82 and Dhanuvit) were sprayed through drone, while manual spraying with battery operated knapsack sprayer was kept for comparison among the treatments. Untreated control with water spray was considered as check.

6.4.3 Data recording:

The standard procedures for recording the incidence of stem borer were followed as mentioned in bio-efficacy experiment. In addition whorl maggot damage was also recorded as mentioned below.

Whorl maggot: Whorl maggot damage was estimated by counting total number of leaves and number of infested leaves per each hill from 10 randomly selected hills. Mean number of damaged leaves and number of leaves were arrived and per cent damaged leaves were calculated.

$$\text{\% Damaged leaves} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves}} \times 100$$

At the time of maturity stage, the grain yield (5 m^2 area at randomly selected in each replication) was recorded and expressed in kg/ha.

Table 6.18. Details of insecticide and adjuvants tested using drone in rice during *rabi,* 2020-21

Trt. No.	Insecticide +Adjuvant	Insecticide dose (ml/l)	Adjuvant dose (ml/l)	Water volume (l/ha)	Equipment for application
T1	Chlorantraniliprole (1X) + Silwet	3.75	3.0	40	Drone
T2	Chlorantraniliprole (1X) + Wetcit	3.75	0.75	40	Drone
T3	Chlorantraniliprole (1X) + Agri-82	3.75	0.5	40	Drone
T4	Chlorantraniliprole (1X) + Dhanuvit	3.75	1.0	40	Drone
T5	Chlorantraniliprole (1X)	0.3	-	500	Battery Operated Knapsack sprayer
T6	UTC	-	-	-	-

The study conducted during *rabi,* 2020-21 revealed that, as far as whorl maggot incidence is concerned, it did not differ significantly among the different treatments. Different adjuvants treatments added to 1X dose of drone spray (T1 to T4) registered significantly higher white ear incidence of stem borer (ranging from 4.15 to 5.00% WE) compared to T5, knapsack spray at 1X dose (2.37% WE). However, significantly highest grain yield was recorded in T2, drone spray @ 1X dose + Wetcit and T5, knapsack spray at 1X dose (7237.5 kg/ha) compared with all other treatments (Table 6.19). It can be inferred from the above data that the addition of tested adjuvants could not improve the performance of Chlorantraniliprole in drone based aerial spraying. However, new adjuvants need to be identified which can improve aerial spraying performance.

Table 6.19. Effect of insecticide in combination with adjuvants on incidence of insect-pests (whorl maggot and stem borer) and grain yield, *rabi,* 2020-21

Treatments	%WMDL (7days after spray)*	%WMDL (14 days after-spray)*	%WE (Pre-harvest)	Grain Yield (kg/ha)
T1 (Drone1X + Silvet)	5.35 (13.36)	4.19 (11.33)	4.15^{b} (11.68)	5950.00^{b}
T2 (Drone1X + Wetsit)	6.63 (14.90)	5.95 (14.08)	5.00b^{c} (12.89)	7437.50^{a}
T3 (Drone1X + Agri- 82)	4.34 (11.91)	3.24 (10.22)	4.80b^{c} (12.58)	5675.00^{b}
T4 (Drone 1X + Dhanuvit)	5.27 (13.20)	3.67 (10.99)	4.34b^{c} (11.95)	5625.00^{b}
T5 (Knapsack1X)	5.89 (13.62)	4.99 (12.86)	2.37^{a} (8.73)	7237.50^{a}
T6 (Untreated control)	6.74 (14.99)	4.50 (12.05)	5.80^{c} (13.90)	5087.50^{b}
CD	-	-	2.15	1231.86
SE(d) ±	NS	NS	1.00	572.72
CV(%)	-	-	11.80	13.13

Chlorantraniliprole 18% SE @ 150ml /ha (1X dose)

6.5 Bio-efficacy of combination of *pesticides* applied through drone against rice stem borer and grain discolouration, *kharif,* 2021

6.5.1 Experimental Details:

Study was conducted at SRTC plots, ARI, Rajendranagar (located adjacent to Rice Research Centre) during *kharif* , 2021 following all standard procedures as mentioned earlier, comprising rice variety Samba Mahsuri (BPT 5204) in 2 ha area, sown on 26.06.2021 and planted on 27.07.2021 with seven treatments in randomized block design, replicated five times (Table 6.20). The best nozzle type identified during SOP studies *viz.,* XR 11002 VP was used for conducting bio-efficacy studies maintaining drone spraying height of 2.5 m and flying speed of 2.8 m/sec and discharge rate of 60% and flow rate of 2.88 L/min.

Table 6.20 Treatment details of insecticide spray (Date of spray: 26.10.2021)

Trt. No.	Treatment	Formulation (ml)	Chemical volume per litre of water	Water volume (l/ha)	Equipment for application
T1	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	2X (2000 g + 1000 ml)	50.00 g + 25.00 ml	40	Drone
T2	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	1.5X (1500 g + 750 ml)	37.50 g + 18.75 ml	40	Drone
T3	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	1X (1000 g + 500 ml)	25.00 g + 12.50 ml	40	Drone
T4	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	0.75X (750 g+375 ml)	18.75 g + 9.375 ml	40	Drone
T5	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	0.5X (500	12.50 g + 6.25 ml	40	Drone
T6	(Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4%SC)	1X (1000 g + 500 ml)	2.00 g + 1.00 ml	500	Knapsack sprayer
T7	UTC	Water spray	-	-	-

6.5.2 Spraying Schedule:

Only one spray of insecticide and fungicide was done at panicle initiation to booting stage on 26.10.2021 (91 DAT) to test the efficacy against stem borer at reproductive stage (white ears) and grain discolouration.

6.5.3 Data recording:

The standard procedures for recording the incidence of stem borer (white ears) were followed as mentioned in bio-efficacy experiment. The per cent grain discolouration was computed as mentioned below, based on the data obtained from five randomly selected panicles in each treatment. At the time of maturity stage, the grain yield (5 m^2 area) was recorded from each treatment and expressed in kg/ha.

$$\text{\% Grain discolouration} = \frac{\text{Number of discoloured grains}}{\text{Total number of grains}} \text{x100}$$

6.5.4 Results:

During *kharif,* 2021, the white ear incidence (WE) ranged from 0.00 to 5.18% across the treatments (Table 6.21). Among the treatments, significantly lowest white ears were noticed in T2, drone spray @1.5X (0.00% WE) followed by T3, 1X (0.17% WE) and both the treatments were on par with each other and significantly different from all the other treatments including untreated control (5.18% WE). The grain discolouration varied from 26.0 to 50.2% between the treatments, while all the drone treatments registered significantly lower grain discoloration (26.0 to 33.0% GD) than untreated control (50.2% GD) and knapsack spray treatment (41.8% GD). The grain yield ranged from 5000 to 7460 kg/ha in different treatments. Significantly highest grain yield was registered at 1X drone spray dose (7460 kg/ha) followed by 1X knapsack dose (7380 kg/ha) and 0.5X drone dose (7320 kg/ha). The higher drone doses *viz.,* 1.5 and 2.0X registered significantly lower grain yield (6380 and 6200 kg/ha, respectively) compared to the above treatments but were significantly superior over untreated control (5000 kg/ha).

Table 6.21: Effect of combination of insecticide and fungicide spraying with drones on incidence of yellow stem borer, grain discolouration and grain yield, *kharif,* 2021

Trt. No.	Name of the treatment	%WE	GD (%)	Yield (Kg/ha)
T1 (Drone)	2.0X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	1.40^{b} (6.61)	26.0^{a} (30.6)	6200^{b}
T2 (Drone)	1.5X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	0.00^{a} (0.00)	27.2^{a} (31.3)	6380^{b}
T3 (Drone)	1X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	0.17^{a} (1.06)	27.4^{a} (31.5)	7460^{a}
T4 (Drone)	0.75X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	2.70c (9.37)	32.8^{a} (35.0)	7220^{ab}
T5 (Drone)	0.5X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	1.37^{b} (6.57)	33.0^{a} (34.9)	7320^{a}
T6 (Knapsack)	1X (Acephate 50% + Imidacloprid 1.8% SP) + (Azoxystrobin 18.2% + Difenoconazole 11.4% SC)	2.85^{bc} (7.79)	41.8^{b} (40.3)	7380^{a}
T7 (Drone)	UTC	5.18^{d} (13.15)	50.2^{c} (45.1)	5000^{c}
	CD at 5% Significance level	1.89	6.80	828.6
	SE(M) ±	0.61	3.30	401.5
	CV %	21.47	15.30	9.50

** Figures in parentheses are arc sine values*

6.6 Bio-efficacy of pesticide combinations applied through drone against rice brown planthopper and grain discolouration, *kharif,* 2021

6.6.1 Experimental Details:

Study was conducted at Maddigatla Village, Boothpur Mandal, Mahabubnagar district (North Latitude: 16°6442; East Longitude 78°1044) during *kharif* 2021 following all standard procedures as mentioned earlier, comprising rice variety Samba Mahsuri (BPT 5204) in 2.8 ha area, sown on 10.06.2021 and planted on 05.07.2021 with 14 treatments in randomized block design, replicated three times. Two nozzle types *viz.,* XR 11002 VP and TP 8002 VP identified during SOP studies were tested in bio-efficacy studies (Fig. 6.18) maintaining drone spraying height of 2.5 m and 2.0 m, respectively and flying speed of 4.4 m/sec, discharge rate of 60% and flow rate of 2.88 litres/min and spray fluid of 40 litres/ha. In power sprayer, spray fluid of 100 litres/ha was used. Accordingly different pesticide doses were computed and used while spraying as per the details mentioned below (Table 6.22).

Table 6.22 Treatment details of insecticide spray (Date of spray: 2.10.2021)

Nozzle	Trt No.	Pesticide details (g or ml/litre of water)
TP 8002VP (Drone) 2.0 m height	T1	Pymetrozine @ 7.5 g + (Tebuconazole + Trifloxystrobin @ 5.0 g)
	T2	Pymetrozine @ 7.5 g + (Picoxystrobin + Tricyclazole @ 25 ml)
	T3	Dinotefuran @ 5 g + (Tebuconazole + Trifloxystrobin @ 5 g)
	T4	Dinotefuran @ 5 g + (Picoxystrobin + Tricyclazole @ 25 ml)
	T5	Triflumezopyrim @ 6 ml + (Picoxystrobin + Tricyclazole @ 25 ml)
	T6	Triflumezopyrim 6 ml + (Tebuconazole + Trifloxystrobin 5.0 g)
XR 11002VP (Drone) 2.5 m height	T7	Pymetrozine 7.5g + (Tebuconazole + Trifloxystrobin 5.0 g)
	T8	Pymetrozine 7.5g + (Picoxystrobin + Tricyclazole 25 ml)
	T8	Dinotefuran 5g + (Tebuconazole + Trifloxystrobin 5.0 g)
	T9	Dinotefuran 5g + (Picoxystrobin + Tricyclazole 25 ml)
	T10	Triflumezopyrim 6 ml + (Tebuconazole + Trifloxystrobin 5.0 g)
	T11	Triflumezopyrim 6 ml + (Picoxystrobin + Tricyclazole 25 ml)
	T12	Pymetrozine 7.5 g + (Tebuconazole + Trifloxystrobin 5.0 g)
Power Sprayer (Flat Fan Nozzle)	T13	Pymetrozine 1.2 g + (Tebuconazole + Trifloxystrobin 0.8 g)
UTC	T14	Water Spray

6.6.2 Spraying Schedule:

Only one spray of insecticide and fungicide was done on 2.10.2021, after noticing that brown planthopper was above ETL and recording observations one day before spraying at booting to flowering stage (89 DAT).

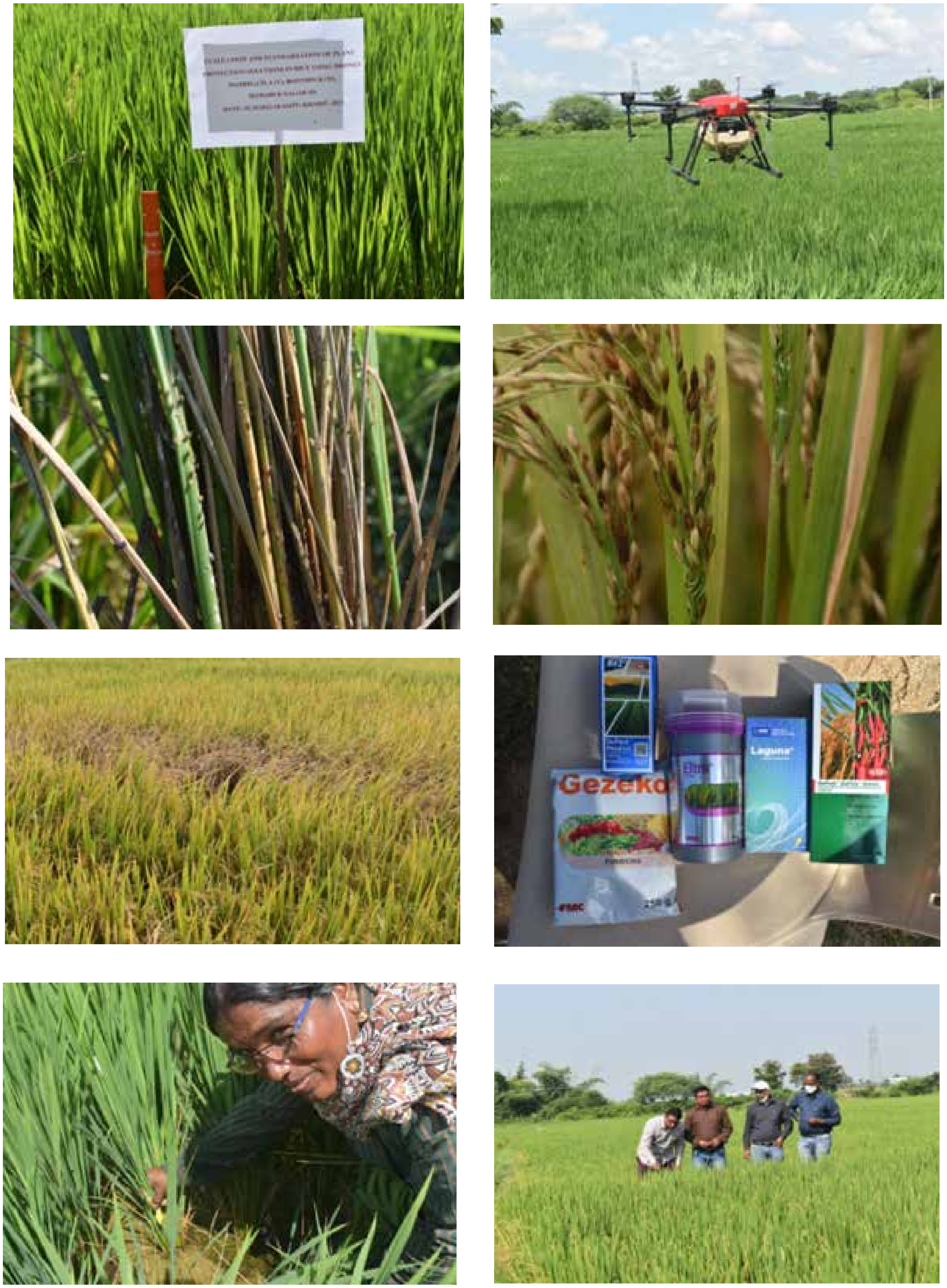


Fig. 6.18 Overview of drone trial conducted at maddigtla village, boothpur mandal, Mahabubnagar district, during *kharif,* 2021

6.6.3 Data recording:

The standard procedures for recording the incidence of brown planthopper (BPH) were followed. The BPH population data (no. of BPH/hill) was recorded from 10 randomly selected hills/ treatment one day before spray, one week and three weeks after spray. To assess the control efficiency of individual pesticide, per cent reduction of BPH in each treatment was computed based on before spray population. The per cent grain discolouration was computed as mentioned below, based on the data obtained from five randomly selected panicles in each treatment. At the time of maturity stage, the grain yield (5 m² area) was recorded from each treatment and expressed in kg/ha.

$$\% \text{ Grain discolouration} = \frac{\text{Number of discoloured grains}}{\text{Total number of grains}} \text{x}100$$

6.6.4 Bio-efficacy of different pesticide combinations applied through drone against rice brown planthopper, *kharif* 2021

The BPH population one day before spray varied from 193.6 to 679.0/ 10 hills across different treatments and in majority of the treatments the BPH population was above ETL. Significantly lowest BPH population per 10 hills one week after spray was noticed in T13, Pymetrozine + (tebuconazole + trifloxystrobin) applied through power sprayer followed by T12, Triflumezopyrim + (picoxystrobin + tricyclazole) drone spray with XR 11002 VP nozzle @ flying height of 2.5 m with 15.2 and 17.4 BPH per 10 hills were on par with each other, while significantly highest population (444.4/ 10 hills) was observed in T14, untreated control (Table 6.23). The above treatments, were followed by T8, T9, T7, T6 and T11 with 19.6, 21.4, 23.2, 23.6 and 26.6 BPH/10 hills, respectively which were on par with each other. The perusal of data on per cent reduction of BPH over before spray clearly indicated that among all the treatments, T12, Triflumezopyrim + (picoxystrobin + tricyclazole) exercised better control of BPH (96.8%), 1 week after spray while T9, T8, T6, T7 and T13 were other superior treatments with per cent reduction ranging from 90.6 to 94.3. The other treatments could reduce BPH by only 52.9 to 88.8%.

Three weeks after spray, the treatments T8, T6, T11, T7 and T12 with 22.0, 22.1, 23.0, 25.8 and 27.8 BPH per 10 hills, respectively registered significantly lower populations as against untreated control (249.4/ 10 hills) and T10 (286.0/10 hills). Close look at the data on per cent reduction of BPH over before spray three weeks after spraying reveals that, treatment T12, Triflumezopyrim + (picoxystrobin + tricyclazole) followed by T8, Pymetrozine + (picoxystrobin + tricyclazole), T7, Pymetrozine + (tebuconazole + trifloxystrobin), T6, Triflumezopyrim + (tebuconazole + trifloxystrobin) and T11, Triflumezopyrim + (tebuconazole + trifloxystrobin) applied through drones exhibited better efficacy against BPH with per cent reduction ranging from 94.8 to 91.1%, whereas the treatment T12, Pymetrozine + (tebuconazole + trifloxystrobin) applied through power sprayer could reduce BPH by 82.8% only. Overall data suggests that among the two nozzle types tested, XR 11002 VP at 2.5 m flying height was better than TX 8002 VP at 2.0 m flying height and suitable for BPH management. Among the pesticide combinations, T12, Triflumezopyrim @6 ml + (picoxystrobin + tricyclazole @ 25 ml)/ l, T8, Pymetrozine @7.5 g + (picoxystrobin + tricyclazole @ 25 ml)/l of water were most suitable for BPH management, while spraying through drones.

Table 6.23.Effect of combination of insecticides and fungicides spraying with drones on incidence of brown planthopper, *kharif*, 2021

Treatment No.	Nozzle Type & Flying Height with Drone	Treatment Details	BPH / 10 hills	BPH / 10 hills	% reduction of BPH in treatment over BS	BPH / 10 hills	% reduction of BPH in treatment over BS
		Pesticide combinations dose in g or ml/ litre of water	Before spray	One week after spray	One week after spray	Three weeks after spray	Three weeks after spray
T1	TX 8002 VP 2.0 m	Pymetrozine 7.5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	290.6^{ab} (16.85)	79.0^{bc} (8.86)	66.6	38.8^{ab} (6.30)	85.1
T2	TX 8002 VP 2.0 m	Pymetrozine 7.5 g + (Picoxystrobin + Tricyclazole 25 ml)	193.6^{a} (13.88)	88.2^{bc} (9.21)	52.9	21.0^{a} (4.67)	89.1
T3	TX 8002 VP 2.0 m	Dinotefuran 5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	340.4^{b} (18.45)	113.6^{c} (10.67)	66.0	65.6^{b} (8.05)	80.4
T4	TX 8002 VP 2.0 m	Dinotefuran 5 g + (Picoxystrobin + Tricyclazole 25 ml)	389.4^{bc} (19.49)	118.8^{c} (10.60)	63.3	82.4^{b} (8.94)	72.5
T5	TX 8002 VP 2.0 m	Triflumezopyrim 6 ml (Picoxystrobin + Tricy1clazole 25 ml)	498.0^{c} (22.19)	51.0^{b} (6.90)	88.3	163.0^{c} (12.78)	65.1
T6	TX 8002 VP 2.0 m	Triflumezopyrim 6 ml +(Tebuconazole + Trifloxystrobin 5.0 g)	306.2^{b} (17.38)	23.6^{ab} (4.94)	92.0	22.01^{a} (4.79)	92.4
T7	XR 11002 VP 2.5 m	Pymetrozine 7.5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	412.0^{bc} (20.24)	23.2^{ab} (4.90)	94.3	25.8^{a} (5.16)	93.4
T8	XR 11002 VP 2.5 m	Pymetrozine 7.5 g + (Picoxystrobin + Tricyclazole 25 ml)	346.4^{b} (18.58)	19.6^{ab} (4.53)	94.2	22.0^{a} (4.78)	93.4
T9	XR 11002 VP 2.5 m	Dinotefuran 5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	400.0^{bc} (19.77)	21.4^{ab} (4.71)	94.3	61.0^{b} (7.63)	82.3
T10	XR 11002 VP 2.5 m	Dinotefuran 5 g + (Picoxystrobin + Tricyclazole 25 ml)	679.0^{d} (25.93)	97.2^{bc} (9.28)	83.3	286.0^{d} (16.52)	58.7
T11	XR 11002 VP 2.5 m	Triflumezopyrim 6 ml + (Tebuconazole + Trifloxystrobin 5.0 g)	292.4^{ab} (16.89)	26.6^{ab} (5.19)	90.6	23.0^{a} (4.89)	91.1
T12	XR 11002 VP 2.5 m	Triflumezopyrim 6 ml + (Picoxystrobin + Tricyclazole 25 ml)	578.0^{cd} (23.83)	17.4^{a} (4.28)	96.8	27.8^{a} (5.24)	94.8
T13	Flat Fan Nozzle (Manual Power Spray)	Pymetrozine 1.2 g + (Tebuconazole + Trifloxystrobin 0.8 g)	217.2^{ab} (14.63)	15.2^{a} (4.00)	92.2	33.8^{ab} (5.88)	82.8
T14 (UTC)	Water Spray	Water Spray	228.4^{ab} (14.96)	444.4^{d} (20.90)	-	249.4^{d} (15.46)	
		CD at 5% significance level	3.42	2.49		2.29	
		SEM(±)	1.20	0.88		0.81	
		CV(%)	14.31	25.15		22.72	

** Figures in parentheses are square root values , DAS- Days after spray*

6.6.5

Bio-efficacy of different pesticide combinations applied through drone against grain discolouration and grain yield, during *kharif,* 2021

The grain discoluration (GD) varied from 8.2 to 35.2 per cent across the treatments (Table 6.24) with two treatments *viz.,* T9, Dintoefuran + (tebuconazole + trifloxystrobin) and T8 Pymetrozine + (picoxystrobin + tricyclazole) recorded lowest per cent grain discolouration (8.2 to 9.2%, respectively) which were significantly superior over all other treatments, including untreated control (35.2% GD). The next best was T3, Dintoefuran + (tebuconazole + trifloxystrobin) with 14.8 per cent grain discolouration while rest of the drone spraying treatments registered grain discoluration ranging from 18.4 to 21.0%.

Perusal of grain yield data (Table 6.22) revealed that among the pesticide combinations tested, significantly higher grain yield was recorded in T11, Triflumezopyrim + (tebuconazole + trifloxystrobin) with XR 11002 VP nozzle, T6, Triflumezopyrim + (tebuconazole + trifloxystrobin) with TP 8002 VP nozzle, T12, Triflumezopyrim + (picoxystrobin + tricyclazole) which were on par with each other realizing grain yield of 9951.8, 9525.0 and 9517.6 kg/ha, respectively and were significantly superior over T14, untreated control (5398.6 kg/ha). The treatments T1, Pymetrozine + (tebuconazole + trifloxystrobin), T4, Dintoefuran +(picoxystrobin + tricyclazole) with TP 8002 VP nozzle, and T7, Pymetrozine + (tebuconazole + trifloxystrobin) with XR 11002 VP nozzle were the next best realizing grain yield ranging from 9207.0 to 8753.2 kg/ha.

It can be deduced from overall data that XR 11002VP nozzle type was best suitable for best suitable for drone spraying for managing BPH and grain discoluration. Insecticides *viz.,* Triflumezopyrim followed by Pymetrozine were compatible with both the fungicide combinations, but there was decrease in efficacy against BPH when dinotefuran was used. Among the fungicides, combination of tebuconazole + trifloxystrobin was most compatible.

6.24 Effect of different pesticide combinations applied through drone on grain discolouration and impact on grain yield, *kharif*, 2021

Treatment Details	Nozzle type & Flying Height with Drone	Treatment	GD (%)	Grain Yield (kg/ha)
		Pesticide combinations dose in g or ml/ litre of water		
T1	TX 8002 VP 2.0 m	Pymetrozine 7.5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	20.2^{c} (26.5)	9207.0^{ab}
T2	TX 8002 VP 2.0 m	Pymetrozine 7.5 g + (Picoxystrobin + Tricyclazole 25 ml)	23.8^{d} (29.1)	8469.2^{b}
T3	TX 8002 VP 2.0 m	Dinotefuran 5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	19.8^{c} (25.8)	8317.4^{b}
T4	TX 8002 VP 2.0 m	Dinotefuran 5 g + (Picoxystrobin + Tricyclazole 25 ml)	14.8^{b} (22.5)	8753.2ab
T5	TX 8002 VP 2.0 m	Triflumezopyrim 6 ml + (Picoxystrobin + Tricyclazole 25 ml)	21.0^{c} (26.9)	7849.0^{b}
T6	TX 8002 VP 2.0 m	Triflumezopyrim 6 ml + (Tebuconazole + Trifloxystrobin 5.0 g)	28.0^{e} (31.9)	9525.0^{a}
T7	XR 11002 VP 2.5 m	Pymetrozine 7.5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	19.4^{c} (26.1)	8944.0^{ab}
T8	XR 11002 VP 2.5 m	Pymetrozine 7.5 g + (Picoxystrobin + Tricyclazole 25 ml)	9.2^{a} (17.6)	8526.0^{b}
T9	XR 11002 VP 2.5 m	Dinotefuran 5 g + (Tebuconazole + Trifloxystrobin 5.0 g)	8.2^{a} (16.6)	7364.0^{b}
T10	XR 11002 VP 2.5 m	Dinotefuran 5 g + (Picoxystrobin + Tricyclazole 25 ml)	18.6^{c} (25.1)	8601.2^{b}
T11	XR 11002 VP 2.5 m	Triflumezopyrim 6 ml + (Tebuconazole + Trifloxystrobin 5.0 g)	19.0^{c} (25.5)	9951.8^{a}
T12	XR 11002 VP 2.5 m	Triflumezopyrim 6 ml + (Picoxystrobin + Tricyclazole 25 ml)	18.4^{c} (25.4)	9517.6^{a}
T13	Flat Fan Nozzle (Manual Taiwan Spray)	Pymetrozine 1.2 g + (Tebuconazole + Trifloxystrobin 0.8 g)	19.6^{c} (26.0)	7854.0^{b}
T14	UTC	Water Spray	35.2^{f} (39.6)	5398.6^{c}
		CD at 5% significance level	5.4	1341.29
		SEM(±)	1.9	471.30
		CV(%)	16.9	12.47

6.7 Studies on phytotoxicity (crop safety evaluation) of insecticides and fungicides and in combinations on rice applied through drones.

6.7.1 Location:

Different experiments were conducted at Kotwalguda, RRC, Rajendranagar and SRTC Rajendranagar to generate information on phytotoxicity during *kharif*, 2020 and *rabi*, 2021 -22. The detailed information on pesticides dosages and combination was presented in Table 6.25.

Table 6.25.Crop safety evaluation of insecticides and fungicides applied using drone in rice during *kharif*, 2020 and *rabi* 2021 -2022

Location	Date of treament	Pesticides tested	Approved dose / ha (1X dose)	Dose tested
Kothwalguda	29.9.2020	Chlorantraniliprole18.5% SC	150 ml	2X and 1X
		Tebuconazole 50% + Trifloxystrobin 25% (75WG)	200 g	2X and 1X
	22.10.2020	Chlorantraniliprole18.5% SC	150 ml	2X and 1X
		Tebuconazole 50% + Trifloxystrobin 25% (75WG)	200 g	2X and 1X
	30.10.2020	Propiconazole 25% EC	500 ml	2X and 1X
RRC, Rajendranagar	22.10.2020	(Mancozeb 50% + Carbendazim 25% WS)+(Acephate 50% + Imidacloprid 1.8 SP)	1250 g + 750 g	2X and 1X
		Cartap hydrochloride 50 SP +(Mancozeb 50% + Carbendazim 25% WS)	1000 g + 1250 g	2X and 1X
SRTC, Rajendranagar	15.03.2022	Cartaphydrochloride+ (Picoxystrobin 7 % + Propiconazole 12% SC)	1000 g + 1000 ml	2X and 1X
		Cartaphydrochloride + (Flupyroxad 62.5 + Epoxiconazole 62.5 EC)	1000 g + 750 ml	2X and 1X
		Cartaphydrochloride+ (Azoxystrobin18.2% w/w + Difenoconazole 11.4% w/w SC)	1000 g + 500 ml	2X and 1X
		Chlorantraniliprole 18.5% w/w SC + (Picoxystrobin 7 % + Propiconazole 12% SC)	150 ml + 1000 ml	2X and 1X
		Chlorantraniliprole 18.5% w/w SC + (Flupyroxad 62.5 + Epoxiconazole 62.5EC)	150 ml + 750 ml	2X and 1X
		Chlorantraniliprole 18.5% w/w SC + (Azoxystrobin18.2% w/w + Difenoconazole 11.4% w/w SC)	150 ml + 500 ml	2X and 1X

6.7.2 Details:

The main objective of the experiment is to generate the phytotoxicity (crop safety) data of most commonly used pesticides in rice when applied alone or in combination using drone as spraying equipment for pesticide formulation which is already approved using knapsack sprayer. The standard package of practices of rice from sowing to harvesting stage of the crop was followed except pesticide spraying. A minimum plot size of 500 m² per replication was selected and buffer zone of 5 m between two plots was maintained to avoid drift and contamination. At least 15-20 m length plots were selected to arrange 4-5 drone flying loops in each treatment. The standard flight parameters such as drone speed (2.8 m/s) and swath width (3 m) were adopted for testing of phytotoxicity of pesticides. The wind speed was measured using Anemometer and temperature, and relative humidity was recorded using hand-held hygrometer. Further, weather data was also collected from ACRC, ARI, Rajendranagar for comparison. The insecticide / fungicides were tested in 2X and 1X recommended dose approved by the CIB & RC and water spray were kept as untreated control.

Observations on phytotoxicity were taken at 1, 3, 5, 7 and 10 days after each spray using 0-10 rating scale (Rajeswaran *et al.*, 2004). The observations were recorded individually for yellowing, stunting, chlorosis, necrosis, wilting, scorching, vein clearing, epinasty and hyponasty *etc.*, as per phytotoxicity rating scale (Table 6.26).

Table 6.26. Phytotoxicity Rating Scale (PRS)

Crop response/ Crop injury	Rating
0	0
1-10%	1
11-20%	2
21-30%	3
31-40%	4
41-50%	5
51-60%	6
61-70%	7
71-80%	8
81-90%	9
91-100%	10

6.7.3 Results on Phytotoxicity

None of the pesticides sprayed using drones either at 1X or 2X dose have shown any phytotoxicity at different doses and combinations tested during *kharif*, 2020 at Kothwalguda and RRC, Rajendranagar. However during *rabi* 2021-22 at SRTC, Rajendranagar, cartap hydrochloride in combination with picoxystrobin + propiconazole or flupyroxad + epoxiconazole or azoxystrobin + difenoconazole have shown phytotoxicity of leaf tips wilting at 2X dose, when sprayed using drones, probably due to clogging of nozzles when wettable powders are used.

Clogging of nozle filters

Leaf tip wilting

Chapter- 7

IMPACT OF AERIAL SPRAYING OF PESTICIDES BY DRONES ON AVIAN FAUNA

Methodology for study on Avian fauna

The rice crop is an ideal habitat for terrestrial and wet land associated bird composition because of more availability of food, feeding sites, roosting, nesting sites especially for insectivorous birds. Indiscriminate use of chemicals may lead to drastic reduction of beneficial birds and can also affect their breeding activity in agricultural landscape. As a part of SOPs, the present study was taken up to assess the impact of insecticides spraying by using drone on avi-fauna. Data on avian fauna (before and after spray) were recorded with the help of AINP on Vertebrate Pest-Management, PJTSAU, Rajendranagar.

Study Area

***Kharif*, 2020:**

The study was conducted at farmer fields *i.e.* Sri. G. Krishna Reddy, Kothwalguda (v), Shamshabad (m), Ranga Reddy district. It is geographically situated at 17.288463° North latitude and 78.376707° East longitude, at an altitude of 542.0 meters above mean sea level.

***Rabi*, 2020-21:**

Agricultural Research Institute (17.329422ON 78.401258OE) and College farm (17.322074O N 78.407341O E) located at Rajendranagar, Hyderabad in semi-arid region of Southern Telangana which are dominated by rice cultivation.

During *kharif,* 2020, pre-spraying survey has been taken up on 28.9.2020 followed by zero day (29.10.2020), 7 days (5.10.2020) and 17 days after 1st spraying (15.10.2020). Second time data was recorded on 21.10.2020 (pre-spraying) followed by zero day of spraying (22.10.2020) and one day after spraying (23.10.2020). One kilometer transect was laid at every 200 m distance, and repeated the same at several locations.

During the observation period bird species were recorded in 20 m radius at duration of 20 min. Various parameters was recorded such as bird species, number of individuals, starting and ending time were recorded. The bird species were identified using binoculars (7x50) and standard field guides (Grimmett *et al.,* 2011). The bird surveys were carried out on regular basis after 2 hr of sunrise and 2 hr before the sunset. Data was also recorded after spraying of insecticide on bird population in relation to their number, richness.

During *rabi,* 2020-21, field survey was conducted from 7.4.2021 to 15.4.2021 to collect data on bird composition check list, abundance and richness of birds in rice fields at ARI using line transect method (Hostetler and Main, 2001). One kilometer transect was laid and at every 200 m distance, and repeated the same at several locations. During the observation period bird species were recorded in 20 m radius at duration of 20 min. Various parameters were recorded such as bird species, number of individuals, starting and ending time were recorded. The bird species were identified using binoculars (7x50) and standard field guides (Grimmett *et al.,* 2011). The bird surveys were carried on regular basis, 2 hr after sunrise and 2 hr before the sunset. Data also recorded after insecticide on bird population in relation to their number, richness before and after spraying of insecticides.

For comparison purpose bird survey was also conducted in un-sprayed area *i.e.* college farm 2 km away from the experimental area. At each location, two persons were involved in collecting the data on the same dates to avoid duplication of the data collection. The BIODIVERSITY-PRO version 2.0 and SPSS software was used for the statistical analysis (Mc Aleece *et al.,* 1997).

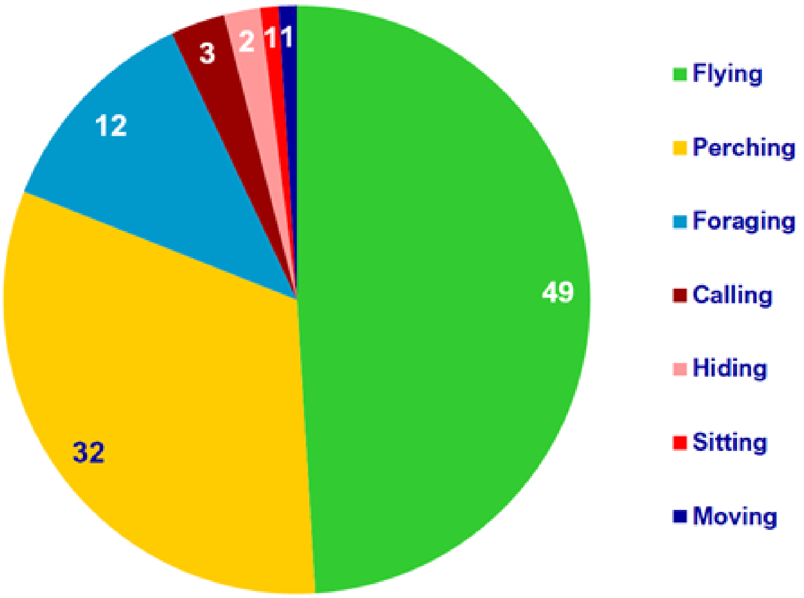


Fig. 7.1. Bird activity pattern in relation to utilization of crops

The food guild showed that 12 species of insectivorous birds are predominant followed by 10 species are Omnivorous, four species are Granivorous and one species is Nectarivorous (Fig. 7.2).

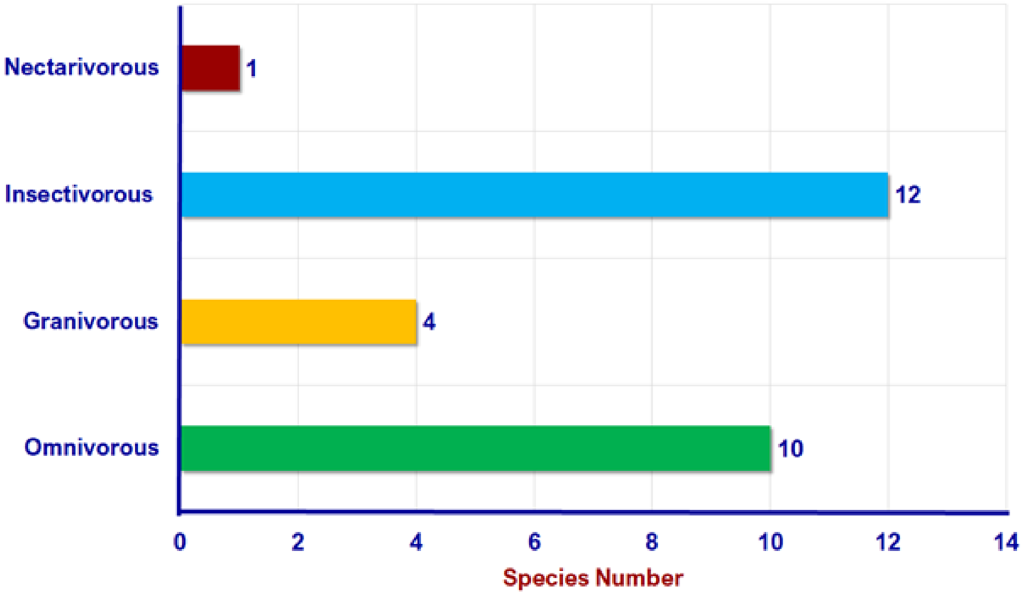


Fig. 7.2. Avian food guilds in the study area

Before spraying in the study area, a total of 22 species with 78 individuals were recorded. Immediately after spraying a total of 9 species with 24 birds were recorded. After a week, the bird count showed an increase in species to the tune of 16 species with a population of 42 individuals and after two weeks the composition of birds to the tune of 12 species. While during the second spray *i.e.*on 22.11.2020 the pre count of 10 bird species with 40 individuals and subsequently reduction of bird numbers was noticed (Table 7.1). The variations are mainly due to the reason that, the chemical smell deters the birds for few days and subsequently the bird count increased after evaporation of the chemical smell. However, no mortality of birds was noticed during the period of study not only at the site location and also around 2 km radius.

Table 7.1. Number of bird species and individuals before and after spraying

	Date	No. of bird species	Bird number
Pre spraying	28.09.2020	22	78
I Spraying	29.09.2020	9	24
7 days after 1st spray	05.10.2020	16	42
17 days after 1st spray	15.10.2020	12	28
Pre spraying	21.10.2020	10	40
II Spraying	22.10.2020	11	46
1 day after 2nd spray	23.10.2020	9	25

During the *rabi,* 2020-21, a total of 28 species of birds belonging to nine orders were observed at college farm location. Among the nine orders, Passeriformes dominated the list with eleven species followed by Peliconiformes and Chardriiformes with five species each and Coraciiformes with two species. The remaining orders, Accipitriformes, Columbiformes, Coraciiformes, Galliformes, Gruiformes and Psittaciformes are represented with one species. Among the total species, fifteen species are common in occurrence while, eight species are abundant in nature, five species are occasional and no species recorded under rare category. The status of birds showed twenty seven species are resident and one species is local migrant. The overall bird activity in the study area showed that 52% of birds were utilizing crop field for foraging, followed by 23% for perching, 17% for flying and 8% calling (Fig 7.3).

The food guild of birds showed that, sixteen species are Omnivorous and predominant followed by insectivorous and granivorous with five species and one species with frugivorous and carnivorous (Fig 7.4). At controlled location *i.e.*college farm, Wood sandpiper was most abundant species (47.53) with highest mean (26.69± 3.52) followed by Cattle egret with mean of 6.38± 2.83 and relative abundance 11%. Ashy prinia, grey francolin, white breasted water hen and white-browed wagtail showed relative abundance of 1% each.

During the period at experimental location, a total of twenty five species of birds belonging to eight orders were observed, of these eight orders, Passeriformes dominated the list with nine species followed by Peliconiformes (6 species), Chardriiformes with three species and Columbiformes and Galliformes with two species each. The remaining orders, Coraciiformes, Gruiformes and Psittaciformes are represented with one species. Predominantly, the birds showed thirteen species are common in occurrence while, eight species are abundant, four species are occasional and no species are rare. Among the status, all twenty five species of birds are residents and no local migrants are recorded. The overall bird activity showed 48% bird, were observed for foraging, followed by 29% for flying 20% perching and 3% calling (Fig 7.5).The food guild showed that, fifteen species are Omnivorous predominant followed by Insectivorous with five species and granivorous with four species and one species with frugivorous (Fig 7.6).

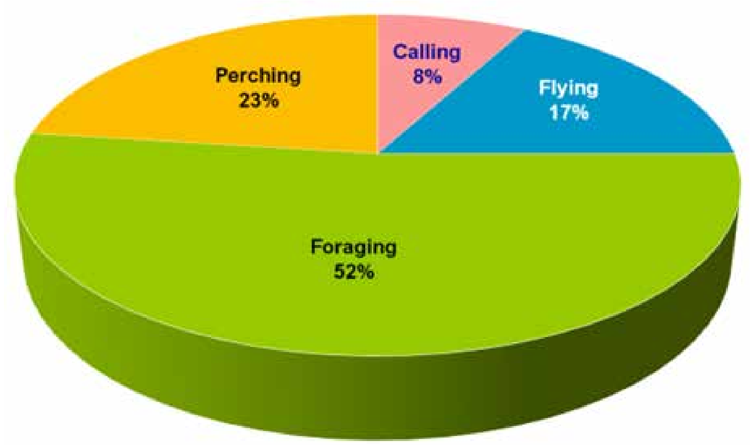


Fig. 7.3. Bird activity pattern in relation to utilization of crops (before spray)

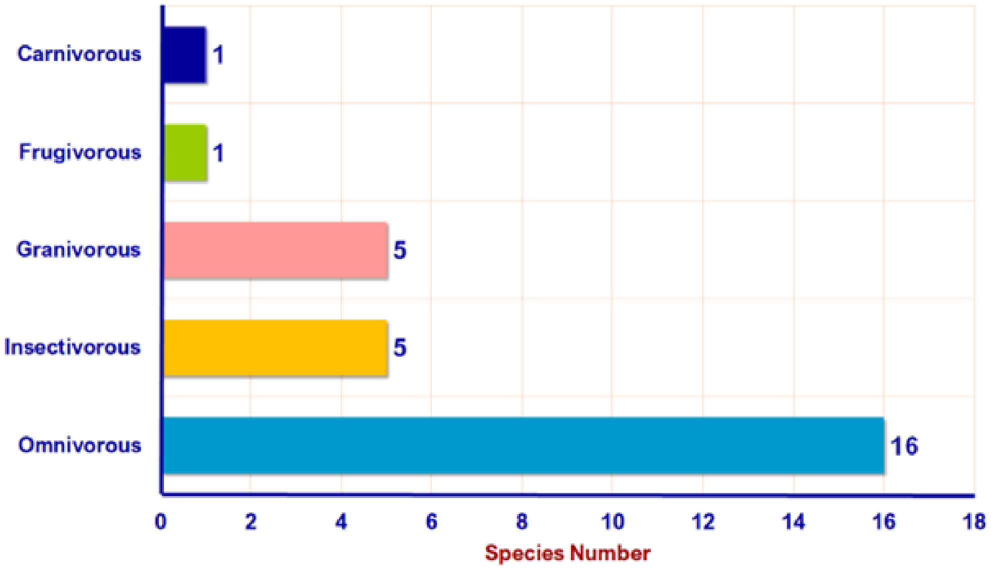


Fig. 7.4. Avian food guilds in the study area (before spray)

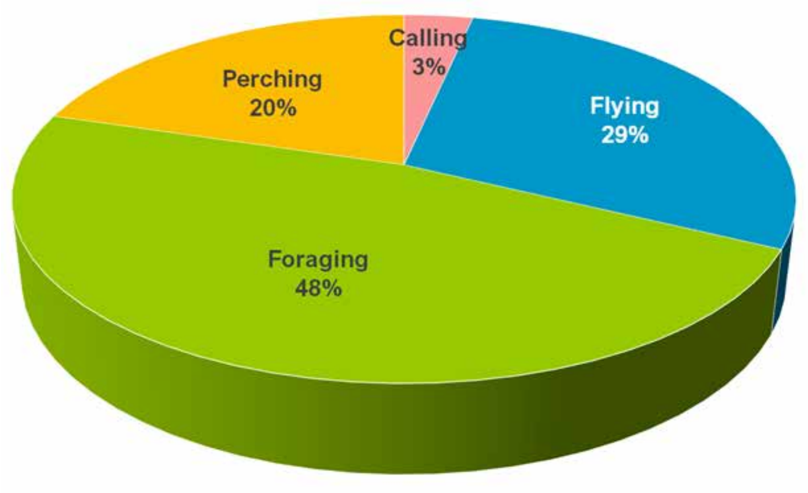


Fig. 7.5. Bird activity pattern in relation to utilization of crops (after spray)

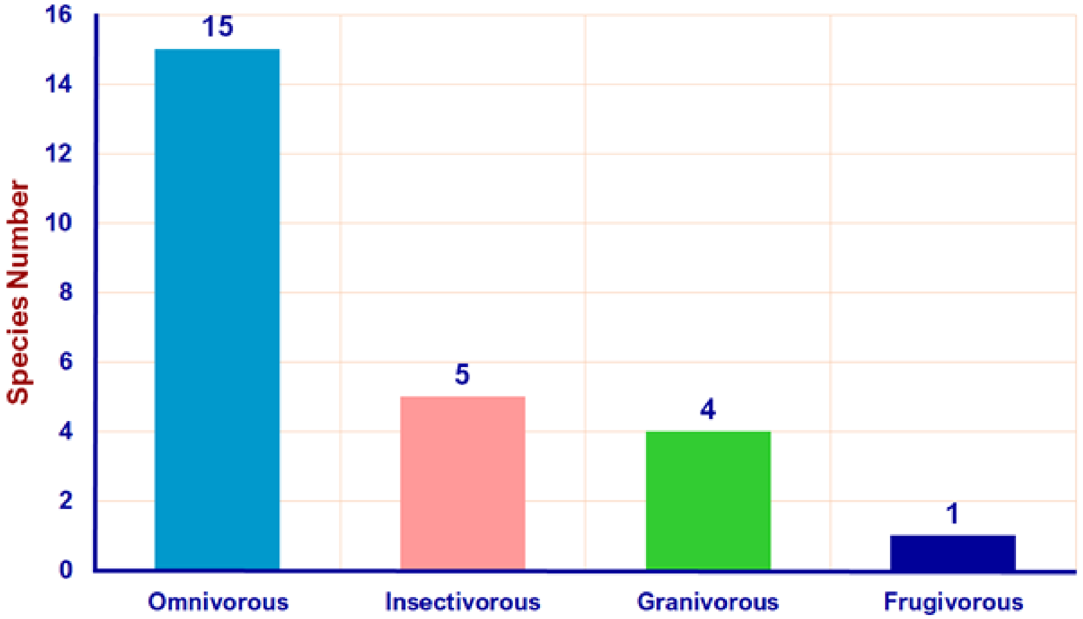


Fig. 7.6. Avian food guilds in the study area (after spray)

The overall mean number of birds recorded in the study area was 5.86 ± 1.33. The mean values are recorded high for sand pipers(19.71 ± 7.41), while the low mean value was recorded for Intermediate egret and white throated kingfisher (1.00 ± 0.00) (Table 7.2).

Table 7.2. Mean number and relative abundance of birds before and after spray

S. No.	Name of the bird	Mean±Sec(Before)	Mean± SE (After)	Relative abundance (Before)	Relative abundance (After)
1	Ashy crowned sparrow lark	1.5 ± 0.50	-	0.84	-
2	Ashy Prinia	1.50 ± 0.50	1.50± 0.50	0.84	0.96
3	Black Drongo	1.9 ± 0.45	2.20± 0.96	5.31	3.54
4	Blue rock pigeon	3.0 ± 1.35	2.25± 0.75	3.35	2.89
5	Cattle Egret	1.66 ± 0.66	1.50± 0.28	1.40	1.93
6	Common crow	1.33 ± 0.33	1.00± 0.00	1.12	0.32
7	Common myna	2.40 ± 0.40	2.50± 0.50	3.35	1.61
8	Common sandpiper	19.71 ± 7.41	-	38.55	-
9	Grey patridge	4.00 ± 2.00	-	2.23	-
10	Indian black ibis	3.00 ± 0.00	-	0.84	-
11	Indian peafowl	2.00 ± 0.00	-	0.56	-
12	Indian Pond Heron	2.00 ± 0.40	1.20± 0.20	2.23	1.93
13	Intermediate egret	1.00 ± 0.00	1.00± 0.00	0.28	0.32
14	Little egret	-	1.00± 0.00	-	0.64
15	Oriental white ibis	2.00 ± 0.00	-	0.56	-
16	Pied bush chat	-	1.00± 0.00	-	1.29
17	Pied starling	-	2.00± 0.00	-	0.64
18	Plain Prinia	-	1.00± 0.00	-	0.64
19	Red wattled lapwing	2.00 ± 0.00	1.33± 0.33	1.12	1.29
20	Rose ringed parakeet	13.80 ± 7.22	14.00± 1.00	19.27	9.00
21	Scaly breasted munia	-	1.00± 0.00	-	0.64
22	Spotted dove	-	1.00± 0.00	-	0.64
23	White breasted Waterhen	2.00 ± 1.00	-	0.64	-
24	White throated kingfisher	1.00 ± 0.00	1.50± 0.50	0.64	0.96
25	Wood sandpiper	12.00 ± 25.00	16.92± 4.20	0.96	70.74
		5.86 ± 1.33	-	-	-

In the experimental sites, before three days prior to spraying, a total of 19 species with 358 individuals were recorded, while after spraying, a total of 18 species with 311 birds were recorded. The marginal variations are mainly due to the reason that, the chemical smell deter the birds for the initial three days and subsequently the bird count has steadily increased. This is due to evaporation of the chemical smell in the fields. Further, no mortality of birds was noticed during the period of study not only at the site location but also around 5km radius around the study location.

After spraying of the insecticide, in the same area the bird count was taken on 10.04.2021 to 15.04.2021 and recorded, wood sand piper with highest mean 16.92 ± 4.20 with relative abundance 70.74% (Table 7.2). Whereas, Ashy crowned sparrow lark, Common sand piper, Grey partridge, Indian black ibis, Indian peafowl, Oriental white ibis and White breasted water hen were not recorded during the period. Whereas, little egret, pied bush chat, pied starling, plain prenia, scaly breasted munia and spotted dove were observed three days after spraying (Table 7.3). The species richness was high at college farm (28 species) and the range of the birds varied from 1–53, while at ARI, the total number of birds recorded with 69 individuals of 25 species and the range of the birds observed from 1–50 (Table 7.4). T-test was performed and the results revealed that there was no significant difference in before and after spray of insecticide (Table 7.5) and also between sprayed and unsprayed locations.

Table 7.3. Mean number and relative abundance of birds at College Farm, Rajendranagar

Name of the bird	Mean ± SE	Number of sightings	Relative Abundance
Ashy crowned sparrow lark	3.00± 0.00	1	0.41
Ashy Prinia	1.00± 0.00	4	0.55
Asian pied Starling	2.00± 0.00	1	0.27
Baya weaver	7.00± 1.61	5	4.79
Black drongo	2.14± 0.55	7	2.05
Black winged kite	1.50± 0.50	2	0.41
Black winged stilt	3.00± 1.00	3	1.23
Blue rock pigeon	5.00± 3.00	2	1.37
Cattle egret	6.38± 2.83	13	11.37
Common myna	1.40± 0.24	5	0.96
Common sandpiper	10.25± 3.88	4	5.62
Green bee-eater	2.00± 0.00	2	0.55
Grey francolin	1.00± 0.00	1	0.14
House crow	5.00± 2.61	4	2.74
Indian black ibis	3.00± 2.00	2	0.82
Indian peafowl	3.25± 0.47	4	1.78
Indian Pond heron	2.00± 0.54	5	1.37
Indian silver bill	11.00± 5.00	2	3.01
Little egret	1.66± 0.33	3	0.68
Little ringed plover	3.00± 0.00	1	0.41
Oriental white Ibis	1.50± 0.50	2	0.41
Plain prinia	1.25± 0.25	4	0.68
Red wattled lapwing	2.20± 0.73	5	1.51
Rose ringed parakeet	6.25± 2.28	4	3.42
Scaly breasted munia	9.00± 4.22	4	4.93
white breasted water hen	1.00± 0.00	3	0.41
White throated kingfisher	1.50± 0.50	2	0.41
White-browed wagtail	1.00± 0.00	1	0.14
Wood sandpiper	26.69± 3.52	13	47.53
Total	**6.69 ± 0.94**	**109**	**100.00**

The study clearly indicated that the bird species richness and composition did not show any variation due to the spraying of insecticides. Further, during the period no mortality of bird species was recorded in the vicinity of 5-kilometer radius. However, a long-term study needs to be conducted for understanding the long-term impact of these molecules on the breeding and feeding aspects of the birds.

Table 7.4. Species richness of birds at College Farm and ARI

Details	ARI, Rajendranagar	College Farm
Richness	25	28
Range	1-50	1-53
Abundance	669	730

Table7.5. One-Sample Test

Details	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
Before spray	3.711	19	0.001	4.179150	1.82236	6.53594
After spray	2.990	19	0.008	2.963100	0.88921	5.03699


Black Drongo (*Dicrurus macrocercus*)
White Throated Kingfisher (*Halcyon smyrnensis*)
Little Egret (*Egretta garzetta*)
Common Myna (*Acridotheres tristis*)
Intermediate Egret (*Ardea intermedia*)
Indian Pond Heron (*Ardeola grayii*)
Ashy Crowned Sparrow Lark (*Eremopterix griseus*)
Plain Prinia (*Prinia inornatat*)
Common Crow (*Corvus splendens*)
Wood Sandpiper (*Tringa glareola*)
Pied Bush Chat (*Saxicola caprata*)
Ashy Prinia (*Prinia socialis*)

Fig. 7.7. Diversity of various avian species documented during drone spraying experiment

Chapter- 8

OVERALL CONCLUSIONS AND FUTURE RESEARCHABLE AREAS

Overall Conclusions

- Based on the studies on droplet parameters with different nozzle types, operated at different flying heights it can be deduced that extended range flat fan nozzle type operated at 110^o angle (XR 11002 VP) was the best in terms of Volume median diameter (315-348 µm), droplet density/cm^2 (43.5, 56.3 and 29.5/cm^2) when operated at 2.5m height above crop canopy at flying speed of 2.8 m/sec. This ensures better crop coverage, less drift and avoids crop lodging while operating the drone. The extended-range flat-fan nozzle is ideal for uniform distribution and for drift control, because they have an excellent spray distribution over a wide range of pressures (15 to 60 *psi*).
- The studies on the effect of different doses of Chlorantraniliprole 18.5 SC against rice yellow stem borer showed that 1X dose @150 ml/ha with drone is more effective than 1X dose of knapsack spray and also realized higher grain yield and accrued better incremental cost benefit ratio. Further, it also clearly brought out that the insecticide dose need not be reduced by 25 or 50% as it is going to impact the bio-efficacy. Further, there is also scope for development of insecticide resistance in the long run when insects are exposed to sub-lethal doses. Therefore, drone operators need to be cautioned not to use reduced insecticide doses while resorting to pesticide spraying with drones.
- The adjuvants tested along with Chlorantrnailiprole 1X dose @ 150 ml/ha could not enhance the bioefficacy against yellow stem borer and there is need to identify new adjuvants for use with drone based pesticides to not only enhance bio-efficacy but also reduce drift of pesticide spray. Further, Chlorantraniliprole was found safe to beneficial fauna (coccinellids, spiders and mirids) when sprayed using drones.
- Similarly, 1X dose of Tebuconazole 50% + Trifloxystrobin 25% (75 WG) @ 200 g/ha drone spray exercised better control of false smut and grain discolouration on par with 1X dose of Knapsack spray and aided in achieving better yields and was more cost effective than Knapsack spraying. Similarly 1X dose of Azoxystrobin 18.2%+ Difenoconazole 11.4% SC @ 500 ml/ha exhibited better efficacy against grain discolouration. However, 1X dose of Propiconazole 25EC @ 500 ml/ha sprayed with drones could contain false smut effectively, but not grain discolouration.
- The studies on phytotoxicity with some of the pesticides registered for tank spray were found safer to the crop at both 1X and 2X doses when sprayed using drones. However, there is need to study all the pesticides registered for use in rice for phytotoxicity and compatibility while spraying using drones.
- Based on the impact assessment of drone based spraying on avian fauna it may be inferred that, even though there was slight decrease in avain faunal diversity post spraying, no mortality of avian populations was observed and restoration was possible within a few days.

Future Researchable Areas

- We observed during the course of study that analysing droplet parameters using water sensitive papers is costly, alternatives need to be identified.
- Studies on developing drone compatible ULV formulations required.
- New adjuvants to enhance pesticide efficacy and reduce drift needed.
- It is essential to evolve strategies to reduce water volume to be used with drones to make drone industry more sustainable.
- The pest detection and diagnosis with drones need to be integrated with drone spraying to reduce pesticide usage through site specific management and promote smart agriculture.
- Complete crop specific package of practices using drones integrating SOPs for foliar nutrition, herbicides, pesticides *etc.*, need to be developed to make it commercially viable industry.

Chapter- 9

STANDARD DRONE AERIAL SPRAY PROTOCOLS FOR CROP PROTECTION IN RICE

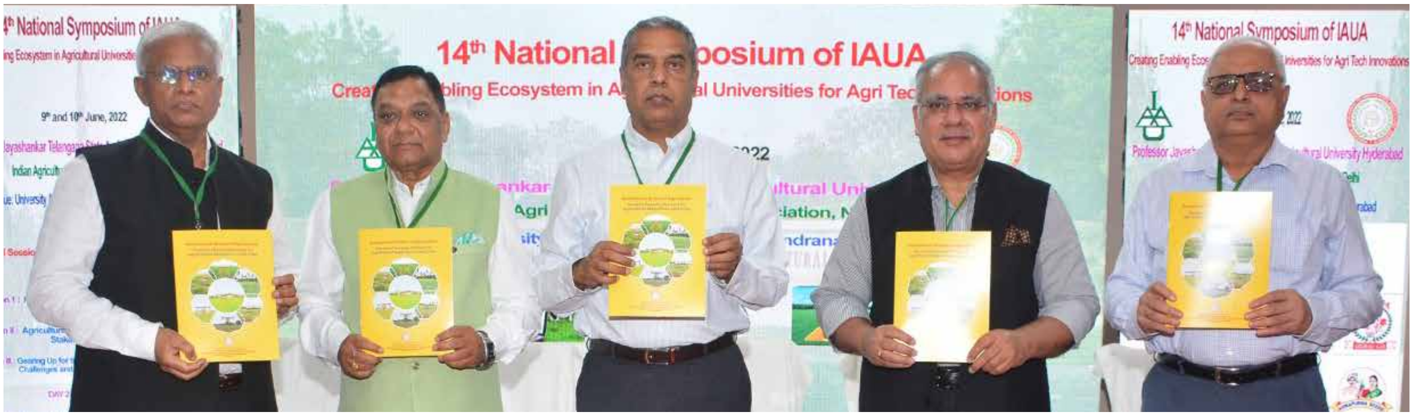


Fig.9.1 Release of Booklet on SOP's for Agrochemical Application in Field Crops

Drone Spray Parameter	Standard Operating Protocol
Location	Rice Research Centre, ARI, Rajendranagar
Agri Startup Partner	Marut Dronetech Pvt. Ltd., Hyderabad
1. Drone Spray Parameters	
Drone Model	AGRICOPTER AG 365 with UIN-UA0013251EX AND HEPICOPTER WITH UIN UA000GU
Nozzle type	XR 11002VP (Extended range – Flat Fan)
Number of nozzles	Four
Optimum flight height above crop canopy	2.5 m
Optimum flight speed	2.8 – 4.4 m/s
Spray Volume At maximum tillering stage After maximum tillering stage	 25 litres/ha 40 litres/ha
Optimum time of spraying	6.00 – 9.00 AM and 3.00 – 6.00 PM
Optimal wind speed for spraying	• Optimal range: 1.0 to 5.0 m/s (3.6 to 18 kmph) • Not suitable for spraying: <1.0 or > 5.0 m/s
2. Pests and Pesticide Formulations	
Stem borer at panicle initiation to booting stage	Chlorantraniliprole 18.5 SC @ 150 ml/ha Acephate 50 + Imidacloprid 1.8 SP @ 750 g/ha

Brown planthopper at reproductive stage	Triflumezopyrim 10 SC @ 240 ml/ha Pymetrozine 50 WG @ 300 g/ha Dinotefuran 50 SG @ 200 g/ha
3. Diseases and Fungicide Formulations	
Grain Discolouration at 25% flowering stage	Tebuconazole 25 + Trifloxystrobin 50 (75 WG) @ 200 g/ha Propiconazole 25 EC @ 500 ml/ha Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500 ml/ha
4. Risk to crop environment	
Phytotoxicity	No crop damage was observed at tested concentrations 1X and 2X doses: Chlorantraniliprole 18.5 SC @ 150 ml/ha, Triflumezopyrim 10 SC @240ml/ha, Pymetrozine 50 WG @ 300g/ha, Dinotefuran 50 SG @ 200g/ha and pesticide combinations of Tebuconazole 50 + Trifloxystrobin 25 (75 WG) @ 200g/ha, Propiconazole 25 EC @ 500ml/ha, Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500ml/ha, Acephate 50 + Imidacloprid 1.8 SP @ 750g/ha, (Mancozeb 50 + Carbendazim 25 WP) @ 1250g + (Acephate 50 + Imidacloprid 1.8 SP) @750g/ha, Chlorantraniliprole 18.5 SC @ 150 ml/ha + (Picoxystrobin 7 + Propiconazole 12 EC @ 1000ml/ha), Chlorantraniliprole 18.5 SC @ 150 ml/ha + (Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 1000ml/h)a, Chlorantraniliprole 18.5 SC @ 150 ml/ha + (Flupyroxad 62.5 + Epoxiconazole 62.5 EC @ 750ml/ha) Cartap Hydrochloride 50 SP @ 1000g + (Mancozeb 50 + Carbendazim 25 WP) @ 1250g/ha, Triflumezopyrim @ 240ml + (Tebuconazole 50 + Trifloxystrobin 25 – 75 WG @ 200g/ha), Triflumezopyrim @ 240ml + (Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500ml/ha), Triflumezopyrim @ 240ml + (Picoxystrobin 6.78 + Tricyclazole 20.33 SC @ 1000ml/ha), Pymetrozine @ 300g + (Tebuconazole 50 + Trifloxystrobin 25 – 75 WG @ 200g/ha), Pymetrozine @ 300g + (Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500ml/ha), Pymetrozine @ 300g + (Picoxystrobin 6.78 + Tricyclazole 20.33 SC) @ 1000ml/ha), Dinotefuran @ 200g + (Tebuconazole 50 + Trifloxystrobin 25 – 75 WG @ 200g/ha), Dinotefuran @ 200g + (Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500ml/ha), Dinotefuran @ 200g + (Picoxystrobin 6.78 + Tricyclazole 20.33 SC @ 1000ml/ha). Cartap Hydrochloride 50 SP @ 1000 g + (Picoxystrobin 7 + Propiconazole 12SC @ 1000ml/ha) or (Flupyroxad 62.5 + Epoxiconazole 62.5EC @ 750ml/ha) or (Azoxystrobin 18.2 + Difenoconazole 11.4 SC @ 500ml/ha), have shown phytotoxicity of leaf tips wilting at 2X dose.
Impact on Beneficial Fauna	Safe to coccinellids, spiders and mirid bugs
Impact on avian fauna	Chlorantraniliprole 18.5 SC, Tebuconazole 50 + Trifloxystrobin 25 (75WG), Propiconazole 25 EC: No mortality was observed, except slight decrease in avain fauna for few days after spray thereafter, restored.
Pesticide residues	Chlorantraniliprole 18.5 SC @ and Tebuconazole 50 + Trifloxystrobin 25 – (75 % WP) not detected in soil and grain
5. Efficiency indices	
Control Efficiency • Drone Spray • Knapsack Spray	 81.8 to 94.8% 71.7 to 82.8%
Field Capacity • Drone Spray • Knapsack Spray	 8 ha/day (20 acres/day) 2 ha/day (5 acres/day)
Water Saving by Drone over Knapsack Spray	92.0 to 95.0%
Labour Productivity • Drone Spray • Knapsack Spray	 4 ha/labour/day (10 acres/labour/day) 1 ha/labour/day (2.5 acres/labour/day)
Saving in time by Drone over Knapsack Spray	75.0%
Yield Improvement by Drone over Knapsack Spray	8.5 to 21.0%

Chapter- 10

GENERAL CONSIDERATIONS THAT AFFECT AERIAL SPRAYING BY DRONES

10.1 Pre-Application

- Confirm not to fly in the drone – forbidden area (airport or electronic station).
- Do not fly drones nearby high-tension electrical lines or cell towers.
- Understand the local aviation laws and regulations, where and how they operate.
- Ensure that the operators are well trained on both drone operation and safe use of pesticide.
- Calibrate drone spray system to ensure nozzle output and accurate application at labeled rates.
- Check and maintain drone in good condition without any leak in the spraying system.
- Confirm place for takeoff and landing, tank mix operations.
- Check and mark the obstacles (walls, trees, electric lines *etc.,*) in and around the field for safe operation.
- Set up at least buffer zone (10 m) between drone treatment and the non-target crop.
- Confirm water sources – Do not spray pesticides near water sources (less than 100 m) to avoid polluting water sources.
- Properly safeguard drinking water bodies, live stock *etc.,* during control operations.
- Use anti- drift nozzle to decrease drift to human and environment.

10.2 During Application

- Read labels carefully to understand safety guidelines
- Confirm the flying route was reasonable to minimize turn around.
- All personal involved in sprays should Wear Personal Protect Equipment (PPE) and spray downwind towards upwind.
- Operation team shall always stay at the downwind end of the field and backlight direction. Non-spraying personal shall be at upwind edge of target area.
- Spray with pure water first to test operate for at least 5 min.
- Two step dilutions required to fully dissolve the pesticide.
- When spraying pesticides that are toxic to non- target organisms such as fish, birds and silkworm, strictly abide by the product label requirements and take effective measures to avoid risks.
- Clean the nozzles frequently when using wettable powders, as they may clog the nozzles and impact the spray performance.
- Adopt proper pressure for optimized droplet spectrum.
- In hilly terrain, make all passes in one direction, down slope. Upslope spraying can be dangerous and should be avoided if possible.

10.3 Do's and Don't's of pesticide applications while using drone.

- Do not fly drone if battery is not in good condition, if tank nozzle and hose pipe are loose.
- Do not fly drone out of the visual range.
- Do not drink alcoholic drinks, 8 hours preceding operation.
- Do not spray during hottest part of the day (11.00 AM to 2.00 PM).
- Do not spray pesticide using drones in the morning (9.00 - 11.00 AM), during flowering stage as it may lead to sterility.
- Do not spray at low wind speeds <1m/sec.
- Do not spray at high wind speeds > 5m/ sec.
- Do not spray during active bee foraging period of the day. Avoid spray drift to flowering nectar crop.
- Do not spray in autonomous mode if the field has tall trees/electric poles, as it may damage propellers.
- Do not spray, if it starts to rain or seems likely to rain soon. A minimum of two hours no rain period required after spraying.
- Do not spray if wind direction changes by >45^0.
- Do not spray during thunderstoms as metel parts and batteries can attract lightning at high altitudes.
- Do not eat, chew, drink or smoke while spraying.
- Do not spray with drone while dropping in or pulling out of a field.
- Do not spray with drone while hovering or circling or unstable.

10.4 Post Application

- Avoid having to walk through crop which has been contaminated by drifting spray.
- Timely evacuation and transfer to fresh air.
- Triple rinse of empty container is mandatory.
- Ensure waste generated is kept to a minimum.
- The disposal of waste must confirm to the local laws.
- Never burn or bury hazardous waste.
- Never leave empty containers in the field. Send triple rinsed empty containers to the nearest approved collection site.
- Set up warming signs in the spray area for reminding people.
- Prevent leakage of plant protection products during transport.
- Securely store plant protection products away from children, unauthorized people, animals and food. Safely dispose all spills immediately.

Literature Cited

- Ahmad, F., Qiu, B., Dong, X., Ma, J., Huang, X., Ahmed, S. and Chandio, F.A. 2020. Effect of operational parameters of UAV sprayer on spray deposition pattern in target and off target zones during outer field weed control application. Computers and Electronics in Agriculture 172:105350. DOI: https://doi.org/10.1016/j.compag.2020.105350

- Aktar, W, Sengupta, D. and Chowdhury, A. 2009. Impact of Pesticides use in Agriculture: Their benefits and hazards. Inter diciplenary Toxicology: 1-12.

- Annegowda D. C., Prasannakumar, M. K., Mahesh, H. B., Siddabasappa, C. B., Devanna, P, Banakar S.N, Manojkumar, H. B., and Rajendra Prasad, S. 2021. Rice Blast Disease in India: Present Status and Future Challenges. In: Integrative Advances in Rice Research Edited by Min Huang. DOI: 10.5772/intechopen.98847.

- Anonymous. 2018. After an erratic monsoon, farmers in nine states struggle with pest outbreaks. Down to Earth. 1 – 14 pp.

- Antuniassi, U.R. 2015. Evolution of agricultural aviation in Brazil. Outlooks on Pest Management 26: 12 – 15.

- Bae, Y. and Koo, Y.M. 2013. Flight attitudes and spray patterns of a roll-balanced agricultural unmanned helicopter. Applied Engineering in Agriculture 29: 675 – 682.

- Baio, F.H.R., Antuniassi, U.R., Castilho, B.R., Teodoro, P.E. and da Silva, E.E. 2019. Factors affecting aerial spray drift in the Brazilian Cerrado. PLOS One 14: 0212289, doi:10.1371/ journal.pone.0212289.

- Baio, F.H.R., Silva, E.E., Vrech, M.A., Souza, F.H.Q., Zanin, A.R. and Teodoro, P.E. 2018. Vegetation indices to estimate spray application rates of crop protection products in corn. Agronomy Journal 110: 1254 – 1259.

- Bashyal, B.M., Aggarwal, R., Banerjee, S., Gupta, S. and Sharma, S. 2014. Pathogenicity, ecology and genetic diversity of the *Fusarium spp.* associated with an emerging bakanae disease of rice *(Oryza sativa L.)* in India. In: Microbial diversity and biotechnology in food security (Kharwar RN et al., Eds.). Springer, New York. pp. 307–314.

- Bentur, J.S., Pasalu, I.C., Sarma, N.P.; Prasada Rao, U., Misra, B. 2003. Gall Midge Resistance in Rice: Current Status in India and Future Strategies-DRR Research Paper Series No. 1/2003; Directorate of Rice Research: Hyderabad, India.

- Bernardes, M.F.F., Pazin, M., Pereira, L.C. and Dorta, D.J. 2015. Impact of Pesticides on Environmental and Human Health. In: Toxicology Studies – Cells, Drugs and Environment; IntechOpen: London, UK, pp. 195–233.

- Bhagat, R.B. 2017. Migration and Urban Transition in India: Implications for Development. UN/POP/EGM/2017/3, United Nations Expert Group Meeting on Sustainable cities, Human mobility and International migration, United Nations Secretariat, New York, USA.

- Bhunkal, N., Singh, Ram. and Mehta, N. (2015). Assessment of losses and identification of slow blighting genotypes against sheath blight of rice. Journal of Mycology and Plant Pathology. 45: 285- 292.

- Blair, A., Ritz, B., Wesseling, C. and Freeman, L.B. 2014. Pesticides and human health. Occupational and Environmental Medicine 72: 81–82.

- Bottrell, D.G. and Schoenly, K.G. 2012. Resurrecting the ghost of green revolutions past: The brown planthopper as a recurring threat to high-yielding rice production in tropical Asia. Journal of Asia-Pacific Entomology 15:122–140.

- BRRI, (2016). Bangladesh Rice Research Institute Annual Report. 2015-2016, Gazipur, BRRI.
- Cao, L. P. 2015. The research progress on machine recognition of plant diseases and insect pests. Chinese Agricultural Science Bulletin 31: 244–249.
- Cao, L., Cao, C., Wang, Y., Li, X., Zhou, Z., Li, F., Yan, X. and Huang, Q. 2017. Visual determination of potential dermal and inhalation exposure using allura red as an environmentally friendly pesticide surrogate. ACS Sustainable Chemistry & Engineering 5: 3882–3889.
- Chand, R. 2012. Agricultural R & D for next generation – ICAR VISION 2020, AU Vice Chancellor and ICAR Meet. New Delhi, India.
- Chand, R. 2017. Doubling Farmer's Income: Rationale, strategy, prospects and action plan. NITI Policy Paper No 1/ 2017, NITI Aayog, New Delhi, India.
- Chander, S., Aggarwal., P.K., Kalra M. and swaruparan 2003. Changes in pest profiles in rice wheat cropping system in Indo-Gangetic Plains. Annals of Plant Protection Sciences 11(2): 258-263.
- Chen, P., Lan, Y., Huang, X., Qi, H., Wang, G., Wang, J., Wang, L. and Xiao, H. 2020. Droplet deposition and control of planthoppers of different nozzles in two-stage rice with a quadrotor unmanned aerial vehicle. Agronomy 10(2):303. DOI: https://dx.doi.org/10.3390/ agronomy10020303.
- Chen, S., Lan, Y., Li, J., Xu, X., Wang, Z. and Peng, B. 2017a. Evaluation and test of the effective spraying width of aerial spraying on plant protection UAV. Transactions of Chinese Society of Agricultural Engineering 33: 82–90 (in Chinese).
- Chen, S., Lan, Y., Li, J., Zhou, Z., Liu, A. and Mao, Y. 2017b. Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying. International Journal of Agricultural Biological Engineering 10: 67–77.
- Chen, H.B., Lan, Y.B., Fritz, B.K., Hoffmann, W.C. and Liu, S.B. 2021. Review of agricultural spraying technologies for plant protection using unmanned aerial vehicle (UAV). International Journal of Agricultural Biological Engineering 14: 38–49.
- Chethana, B.S., Deepak, C.A., Rajanna, M.P., Ramachandra, C. and Shivakumar, N. 2016. Current scenario of rice diseases in Karnataka. International Journal of Science and Nature 7: 405 – 412.
- CPCRI. 2019. Invasion of rugose spiralling whitefly (*Aleurodicus rugioperculatus* Martin) in South India. Available at http://cpcri.gov.in/index.php/rti/9-uncategorised/591.
- da Cunha, J.P.A.R., de Alvarenga, C.B., Rinaldi, P.C.N., Marques, M.G. and Zampiroli, R. 2021. Use of remotely piloted aircrafts for the application of plant production products. Engineering Agriculture 41: 245 – 254.
- Damalas, A. and Koutroubas, S.D. 2016. Farmers' exposure to pesticides: Toxicity types and ways of prevention. Toxics 4: 1; doi:10.3390/toxics4010001.
- Damalas, C.A. and Eleftherohorinos, I.G. 2011. Pesticide exposure, safety issues, and risk assessment indicators. International Journal of Environmental Research and Public Health 8: 1402 – 1419.
- De, A., Bose, R., Kumar, A. and Mozumdar, S. (eds). 2014. Worldwide pesticide use. In: Targeted delivery of pesticides using biodegradable polymeric nanoparticles. Springer, Berlin, pp 5–6.

- Devi, P.I., Thomas, J. and Raju, R.K. 2017. Pesticide Consumption in India: A Spatiotemporal Analysis. Agricultural Economics Research Review 30: 163 – 172.
- Dhaliwal, G.S., and Koul, O., 2010. Quest for pest management from green revolution. Kalyani Publishers, New Delhi – Agricultural Pests – 386 Pages.
- Dhaliwal, G.S., Jindal, V. and Mohindru, B. 2015. Crop Losses due to insect pests: global and Indian scenario. Indian Journal of Entomology 77: 165 – 168.
- Dodan D.S., and Singh, R. 1996. False smut of rice: Present status. Agric. Rev. 17: 227–240.
- Dou, H., Zhang, C., Li, L., Hao, G., Ding, B., Gong, W. and Huang, P. 2018. Application of variable spray technology in agriculture. IOP Conference Series: Earth and Environmental Science 186:012007. doi:10.1088/ 1755-1315/186/5/012007.
- DPPQ. 2020. Directorate of Plant Protection, Quarantine & Storage: Statistical database. Available at http://ppqs.gov.in/statistical-database).
- Fand, B.B., Nagrare, V.S. and Gawande, S.P. 2019. Widespread infestation of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) on Bt cotton in central India: a new threat and concerns for cotton production. Phytoparasitica 47: 313–325.
- FICCI, 2020. Technical Discussion Paper on Drone Usage for Agrochemical Spraying, July 2020. Crop Life India, New Delhi. https.//ficci.in/spdocument/23308FICCI-Croplife-Technical-Discussion-paper.pdf
- Fritz, B. K., Hoffmann, W. C., Martin, D. E., and Thomson, S.J. 2007. Aerial application methods for increasing spray deposition on wheat heads. Applied Engineering in Agriculture 23(6): 709-715.
- Ghugare, B.D., Adhaoo, S.H., Gite, L.P., Pandya, A.C. and Patel, S.L. 1991. Ergonomics evaluation of a lever-operated knapsack sprayer. Applied Ergonomics 22: 241–250.
- Gil, E., Arno, J., Llorens, J., Sanz, R., Llop, J., Rosell-Polo, J.R., Gallart, M. and Escola, A. 2014. Advanced technologies for the improvement of spray application techniques in Spanish viticulture: An overview. Sensors (Switzerland) 14: 691-708.
- Giles, D. and Billing, R. 2014. Deployment and performance of an unmanned aerial vehicle for spraying of specialty crops. In: Proceedings of the International Conference of Agricultural Engineering, Zurich, Switzerland, 6–10 July 2014.
- Giles, D. and Billing, R. 2015, Deployment and performance of a UAV for crop spraying. Chemical Engineering Transactions 44: 307 – 312.
- GOI, 2021. Standard Operating Procedure for use of drone application with pesticides for crop protection and for spraying soil and crop nutrients for agricultural, forestry and non-cropped areas etc,.https://agricoop.nic.in/sites/default/files/SOP%20for%20Drone_2. pdf
- Grimmett R., Inskipp C. and Inskipp. T 2011. Birds of the Indian Subcontinent. 2nd ed. London: Oxford University Press & Christopher Helm. Pp. 1–528.
- Gupta, A.K., Solanki, I.S., Bashyal, B.M., Singh, Y. and Srivastav, K. 2015. Bakanae of rice -an emerging disease in Asia. Journal of Animal and Plant Sciences 25:1499 – 1514.

- Hassanalian, M. and Abdelkefi, A. 2017. Classifications, applications, and design challenges of drones: A review. Progress in Aerospace Sciences 91: 99 – 131.
- Hostetler, M.E. and Main, M.B. 2001. Florida Monitoring Program: Point Count Method to Survey Birds. Institute of food and agriculture science, University of Florida. Gainesville.
- Hu, G., Lu, F., Zhai, B. P., Lu, M. H., Liu WC., Zhu F et al. (2014). Outbreaks of the brown planthopper, *Nilaparvata lugens* in the Yangtze river d ? PLOS ONE 9:@ 88973.doi:10.1371/Journal. Pme. 0088973.
- Huang, Y.B., Thomson, S.J., Hoffmann, W.C., Lan, Y.B. and Fritz, B.K. 2013. Development and prospect of unmanned aerial vehicle technologies for agricultural production management. International Journal of Agricultural Biological Engineering 6: 1–10.
- Hunter, J.E., Gannon, T.W., Rochardson, R.J., Yelverton, F.H. and Leon, R.G. 2020. Coverage and drift potential associated with nozzle and speed selection for herbicide applications using an unmanned aerial sprayer. Weed Technology 34: 235–240
- Hunter, M.C., Smith, R.G., Schipanski, M.E., Atwood, L.W. and Mortensen, D.A. 2017. Agriculture in 2050: recalibrating targets for sustainable intensification. Bioscience 67: 386–391.
- Hussain, S., Cheema, M.J.M., Arshad, M. and Chatta, A.A. 2019. Spray uniformity testing of unmanned aerial spraying system for precise agrochemical applications. Pakistan Journal of Agricultural Sciences 56:897 – 903.
- Islam, Z., Rahman, M.A., Barrior, A.T., Polaszek, T., Chancellor, K.L, Heong M., *et al.,* 2003. Diversity of arthropods in irrigated rice in Bangladesh. Bangladesh Journal of Entomology 13, 1-25.
- Jorge, M.G., Pablo, A., Juan, A. and Manuel, P.R. 2019. Spray and economics assessment of a UAV-based ultra-low volume application in olive and citrus orchards. Precision Agriculture 6: 1–18.
- Joshi, S., Pai, S.G., Deepthy, K.B., Ballal, C.R. and Watson, G.W. 2020. The cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Coccomorpha: Pseudococcidae) arrives in India. Biotaxa 4772: 191 – 194.
- Kim, K.H., Kabir, E. and Jahan, S.A. 2017. Exposure to pesticides and the associated human health effects. Science of the Total Environment 575: 525 – 535.
- Kim H G., Park J S and Lee. D. H. 2019. Potential of Unmanned Aerial Sampling for Monitoring Insect Populations in Rice Fields. Florida Entomologist, 101(2) : 330-334.
- Kitpo N and Inoue M 2018. Early rice disease detection and position mapping system using drone and IOT architecture. In: 12th South East Asian Technical University Consortium Symposium (SEATUC), Yogyakart, Indonesia.
- Kumarnath, K.V. 2020. Whitefly devastates palm oil; yield dips. Business line 21 March, 2020. Available at https://www.pressreader.com/india/the-hindu-business-line / 20200321 / 282046214180331.
- Ladhalakshmi D., Laha. G.S., Singh R., Karthikeyan A., Mangrauthia S.K., Sundaram RM, Thukkaiyannan P, Viraktamath BC. 2012. Isolation and characterization of *Ustilaginoidea virens* and survey of false smut disease of rice in India. Phytoparasitica. 40:171–176.
- Lamichhane, J.R. 2017. Pesticide use and risk reduction in European farming systems with IPM: An introduction to the special issue. Crop Protection 97: 1–6.

- Lan, Y. and Chen, S. 2018. Current status and trends of plant protection UAV and its spraying technology in China. International Journal of Precision Agricultural Aviation 1: 1–9.
- Lan, Y. and Wang, G. 2018. Development situation and prospects of China's crop protection UAV industry. Agricultural Engineering Technology 38: 17–27 (In Chinese).
- Lan, Y., Shengde, C. and Fritz, B.K. 2017. Current status and future trends of precision agricultural aviation technologies. International Journal of Agricultural Biological Engineering 10: 1–17
- Lee, H.J. 2017. The Fourth Industrial Revolution and the Future of Agriculture. Smart Farm and Shared Economy. Rep. of Korea: Science and Technology Policy Institute.
- Lejon, E. and Frankelius, P. 2015. Sweden innovation power – Agritechnica 2015. Jonkoping: Elmia.
- Li X., Andaloro, J, T, Lang, E. B . and Pan Y 2019. "Best Management Practices for Unmanned Aerial Vehicles (UAVs) Application of Insecticide Products on Rice and Other Field Crops" An ASABE Meeting Presentation DOI: Paper Number: 1901493 https://doi.org/10.13031/aim.20 1901493.
- Liao, J., Zang, Y., Luo, X., Zhou, Z., Lan, Y., Zang, Y., Gu, X., Xu, W. and Hewitt, A. 2019. Optimization of variables for maximizing efficacy and efficiency in aerial spray application to cotton using unmanned aerial systems. International Journal of Agricultural and Biological Engineering 12:10 – 16.
- Liao, J., Zang, Y., Zhou, Z.Y. and Luo X W. 2015. Quality evaluation method and optimization of operating parameters in crop aerial spraying technology. Transactions of the Chinese Society of Agricultural Engineering 31(Supplement 2): 38–46 (in Chinese).
- Liu T., Shi T., Zhang H., and Wu C 2020. Detection of rice damage by leaf folder *(Cnaphalocrocis medinalis)* using unmanned aerial vehicle based hyperspectral data. Sustainability 12, 9343; doi:10.3390/su12229343
- Lou, Z., Xin, F., Han, X., Lan, Y., Duan, T. and Fu, W. 2018. Effect of unmanned aerial vehicle flight height on droplet distribution, drift and control of cotton aphids and spider mites. Agronomy 8: 187.
- Mahmood, I., Imadi, S.R., Shazadi, K., Gul, A. and Hakeem, K.R. 2016. Effects of pesticides on environment. In Plant, Soil and Microbes, Vol. 1: Implications in Crop Science, ed. K.R Hakeem, M.S Akhtar, SNA Abdullah, pp. 253–69. Cham, Switz.: Springer Intl. Publ.
- Maikaensarn V and Chantharat M 2020. Effectiveness analysis of drone use for rice production in central Thailand. In: Sakata, Shozo ed 2020. Structural changes of Agriculture in the CLMTV Countries and their Socio-Economic Impacts, BRC Research Report, Bangkok Report, Bangkok Research Centre, Jetro, Bangkok/IDE-JETRO.
- Markle, J. C., Niederholzer, F. J., and Zalom, F. G. (2016). Evaluation of spray application methods for navel orange worm control in almonds. Pest Management Science 72: 2339–2346.
- Martin, D.E., Woldt, W.E. andLatheef, M.A. 2019. Effect of application height and ground speed on spray pattern and droplet spectra from remotely piloted aerial application systems. Drones 3:83. DOI: https://doi.org/10.3390/drones3040083
- McAleece N., Gage J. D, Lambshead J, and Patterson G. L. J. 1997. Biodiversity Professional. The Natural History Museum & The Scottish Association for Marine Science.

- Meng, Y., Lan, Y., Mei, G ., Guo, Y., Song, J and Wang, Z. 2018. Effect of aerial spray adjuvant applying on the efficiency of small unmanned aerial vehicle for wheat aphids control. International Journal of Agricultural and Biological Engineering 11:46-53.
- Min S, Lee, SW., Choi, BR., Lee SH, Kwon DH. 2014. Insecticide resistance monitoring and correlation analysis to select appropriate insecticides against *Nilaparvata lugens* (Stal), a migratory pest in Korea. Journal of Asia Pacific Entomology. 17:711-716
- Mohanty, M.K., Behera, B.K., Jena, S.K., Srikanth, S., Mogane, C., Samal, S. and Behera, A.A. 2013. Knowledge attitude and practice of pesticide use among agricultural workers in Puducherry, South India. Journal of Forensic and Legal Medicine 20: 1028-1031.
- Mondal, D., Ghosh, A., Roy, D., Kumar, A., Shamurailatpam, D., Bera, S., Ghosh, R., Bandopadhyay, P. and Majumder, A. 2017. Yield loss assessment of rice (*Oryza Sativa L.*) due to different biotic stresses under system of rice intensification (SRI). Journal of Entomology and Zoology Studies 5: 1974 – 1980.
- Muralidharan K., and Pasalu, I. C. 2006. Assessments of crop losses in rice ecosystems due to stem borer damage (Lepidoptera: Pyralidae). Crop Protection 25 (5): 409-417.
- Padmavathi, C., Gururaj K., Padmakumari A P, Voleti S. R. and Subba Rao L.V, 2013. The effect of leaf folder *Cnaphalocrocis medinalis* (Guenee) [Lepidoptera: Pyralidae] injury on the plant physiology and yield loss in rice.Journal of Applied Entomology. 137, 249–256.
- Prakash, A., Rao, J., Berliner, J., Mukherjee, A., Adak, T., Lenka, S., Singh, N.K. and Nayak, U.K. 2014. Emerging pest scenario in rice in India. Journal of Applied Zoological Research 25:179 – 181.
- Pretty, J. and Bharucha, Z.P. 2015. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects 6:152– 182.
- Qin, W., Qiu, B., Xue, X., Chen, C., Xu, Z. and Zhou, Q. 2016. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against planthoppers. Crop Protection 85: 79–88.
- Qiu, B.J., Wang, L.W. and Cai, D.L. 2013. Effect of flight altitude and speed of unmanned helicopter on spray deposition uniform. Transactions of the Chinese Society of Agricultural Engineers 29: 25–32 (in Chinese).
- Rajeswaran, J., Santharam, G., and Chandrasekran S. 2004. Studies on compatibility and phytotoxocity of carbosulfan 25 EC with certain agrochemicals on cotton. Journal of Entomological Research 28(3):247-252.
- Rajarajeswari, N.V. and Muralidharan K., 2006. Assessments of farm yield and district production loss from bacterial leaf blight epidemics in rice. Crop Protection 25 (3): 244-252. DOI:10.1016/j.cropro.2005.04.013.
- Sanchez-Hermosilla, J., Rincón, V.J., Paez, F. and Fernandez, M. 2012. Comparative spray deposits by manually pulled trolley sprayer and a spray gun in greenhouse tomato crops. Crop Protection 31: 119–124.
- Sankaran, S., Khot, L.R., Espinoza, C.Z., Jarolmasjed, S., Sathuvalli, V.R and Vandemark, G.J., 2015. Low-altitude, high-resolution aerial imaging systems for row and field crop phenotyping: A review. European Journal of Agronomy 70:112–123.
- Sarri, D., Martelloni, L., Rimediotti, M., Lisci, R., Lombardo, S. and Vieri, M. 2019. Testing a multi-rotor unmanned aerial vehicle for spray application in high slope terraced vineyard. Journal of Agricultural Engineering 50: 38–47.

- Savary. S., Willocquet, L., Pethybridge, S.J., Esker, P., McRoberts, N. and Nelson, A. 2019. The global burden of pathogens and pests on major food crops. National Ecology & Evolution 3:430 – 439.
- Selvaraj, K., Venkatesan, T., Sumalatha, B.V. and Kiran, C.M. 2019. Invasive Rugose Spiralling whitefly (*Aleurodicus rugioperculatus* Martin), A serious pest of oil palm (*Elaeis guineensis*) in India. Journal of Oil Palm Research 31: 651 – 656
- Shamshiri, R. R., Hameed, J.A., Balasundaram, S.K., Ahmad D., Weltien, E., and Yamin, M. 2018. Fundamental research on unmanned aerial vehicles to support precision agriculture in oil palm plantations. In:Agricultural Robots: Fundamentals and Applications (J. Zhou and B. Zhang, eds.,) Intech Open.
- Sheng, C.F., Xuan, W.J., Jiao, X.G., Su, J.W., Shao, Q.C., Song, F.B., 2002. Causes, trend and control strategies of disaster of rice borers in China. Journal of Natural Disasters 11: 103e108.
- Sheoran, O.P; Tonk, D.S; Kaushik, L.S; Hasija, R.C and Pannu, R.S 1998. Statistical Software Package for Agricultural Research Workers. Recent Advances in information theory, Statistics & Computer Applications by D.S. Hooda & R.C. Hasija Department of Mathematics Statistics, CCS HAU, Hisar (139-143).
- Subramanian, K. S., Pazhanivelan, S., Srinivasan, G., Santhi, Rand Sathiah, N. 2021. Drones in insect pest management. Frontiers in Agronomy Pp 1-12. https://doi.org/10.3389/fagro.2021.640885.
- Tang, Y., Hou, C.J., Luo, S.M., Lin, J.T., Yang, Z. and Huang, W.F. 2018. Effects of operation height and tree shape on droplet deposition in citrus trees using an unmanned aerial vehicle. Computers and Electronics in Agriculture 148: 1–7.
- Tanwar, R.K., Prakash, A., Panda, S.K., Swain, N.C., Garg, D.K., Singh, S.P., Satya Kumar, S., and Bambawale, O.M. 2010. Rice swarming caterpillar (*Spodoptera mauritia*) and its management strategies. Technical bulletin 24. NCIPM, New Delhi.
- Teng, P S., Heong, K L., Moody, K., 1993. Advances in tropical rice integrated pest management research. In: New frontiers in rice research. Ed. By Muralidharan K, Siddiq, E. A ., Directorate of Rice Research, Hyderabad, India 241-245.
- Torrent, X., Garcera C., Molto E., Chueca, P., Abad, R. and Grafulla, C., 2017. Comparison between standard and drift reducing nozzles for pesticide application in citrus: Part I. Effects on wind tunnel and field spray drift. Crop Protection 96, 130–143.
- Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., Chu, C. and Phung, D.T. 2021. Agriculture Development, Pesticide Application and Its Impact on the Environment. International Journal of Environmental Research and Public Health 18: 1112. https://doi.org/10.3390/ ijerph18031112.
- United Nations, Department of Economic and Social Affairs, Population Division 2019. World Population Prospects 2019, Online Edition. Rev. 1.
- Wang, C. L., He, X. K., and Wang, X. N. 2016. Testing method of spatial pesticide spraying deposition quality balance for unmanned aerial vehicle. Transactions of Chinese Society of Agricultural Engineers 32: 54–61.
- Wang, G., Lan, Y., Qin H., Chen, P., Hewitt, A and Han, Y. 2018. Field evaluation of an unmanned aerial vehicle (UAV sprayer: Effect of spray volume on deposition) and control of pests and diseases in Wheat. Pest management Science 75: 1546-1555.

- Wang, L., Lan, Y., Zhang, Y., Zhang, H., Tahir, M.N., Ou, S., Liu, X. and Chen, P. 2019a. Applications and prospects of agricultural unmanned aerial vehicle obstacle avoidance technology in China. Sensors 19: 642.
- Wang, G.B., Lan, Y.B., Qi, H.X., Chen, P.C., Hewitt, A. and Han, Y.X. 2019b. Field evaluation of an unmanned aerial vehicle (UAV) sprayer: Effect of spray volume on deposition and the control of pests and disease in wheat. Pest Management Science 75:1546–1555.
- Wang, G., Lan, Y., Yuan, H., Qi, H., Chen, P., Ouyang, F. and Han, Y. 2019c. Comparison of spray deposition, control efficacy on wheat aphids and working efficiency in the wheat field of the unmanned aerial vehicle with boom sprayer and two conventional knapsack sprayers. Applied Sciences 9: 218. doi:10.3390/app9020218
- Wang, G., Li, X., Andaloro, J., Chen, P., Song, C., Shan, C., Chen, S. and Lan, Y. 2020. Deposition and biological efficacy of UAV-based low-volume application in rice fields. International Journal of Agricultural and Biological Engineering 3: 65 – 72.
- Wang, J., Lan, Y.B., Wen, S and Hewitt, A J. 2020. Meteorological and flight altitude effects on deposition, penetration, and drift in pineapple aerial spraying. Asia Pacific Journal of Chemical Engineering 15: e2382. doi: 10.1002/apj.2382
- Wang, S., Li, X., Zeng, A., Song, J., Xu, T., Lv, X. and He, X. 2022. Effects of Adjuvants on Spraying Characteristics and Control Efficacy in Unmanned Aerial Application. Agriculture, 12, 138. https://doi.org/10.3390/ agriculture12020138
- Way, M. J. and Heong, K. L. 1994. The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice – a review. Bulletin of Entomological Research 84: 567–587.
- Wen, S., Zhang, Q., Deng, J., Lan, Y., Yin, X. and Shan, J. 2018. Design and experiment of a variable spray system for unmanned aerial vehicles based on PID and PWM Control. Applied Sciences 8: 2482.
- Xin, F., Zhao, J., Zhou, Y., Wang, G., Han, X., Fu, W., Deng, J. and Lan, Y. 2018. Effects of dosage and spraying volume on cotton defoliants efficacy: A case study based on application of unmanned aerial vehicles. Agronomy 8: 85
- Xue, X., Lan, Y., Sun, Z., Chang, C. and Hoffmann, W. 2016. Develop an unmanned aerial vehicle based automatic aerial spraying system. Computers and Electronics in Agriculture 128: 58–66.
- Yang, S., Yang, X. and Mo, J. 2018. The application of unmanned aircraft systems to plant protection in China. Precision Agriculture 19: 278–292
- Xue, Y., Tu. K., Qin, W. C., Lan Y. B. and Zhang, H. H. 2014. Drift and deposition of ultra low altitude and low volume application in paddy field. International Journal of Agricultural and Biological Engineering. 7:23-28.
- Zhang, H., Qi, L., Wu, Y., Musiu, E.M., Cheng, Z. and Wang, P. 2020b. Numerical simulation of airflow field from a six-rotor plant protection drone using lattice Boltzmann method. Biosystems Engineering 197: 336-351.
- Zhang, X.-Q., Song, X.-P., Liang, Y.-J., Qin, Z.-Q., Zhang, B.-Q., Wei, J.-J., Li, Y.-R. and Wu, J.-M. 2020b. Effects of spray parameters of drone on the droplet deposition in sugarcane canopy. Sugar Tech 22: 583 – 588.
- Zhang, B., Tang, Q., Chen, L., Zhang, R. and Xu, M. 2018. Numerical simulation of spray drift and deposition from a crop spraying aircraft using a CFD approach. Biosystems Engineering 166: 184 – 199.
- Zhang, C. and Kovacs, J.M. 2012. The application of small unmanned aerial systems for precision agriculture: a review. Precision agriculture 13: 693 – 712.

- Zhang, X., Zhao, W., Jing, R., Wheeler, K., Smith, G.A., Stallones, L. and Xiang, H. 2011. Work-related pesticide poisoning among farmers in two villages of Southern China: A cross-sectional survey. BMC Public Health 11: 429.
- Zhang, D.Y., Lan, Y.B. and Chen, L.P. 2014. Current status and future trends of agricultural aerial spraying technology in China. Transactions of the CSAM 45: 53–59 (in Chinese).
- Zhang, P., Zhang, W., Sun, H., Fu, H. and Liu, J. 2021. Effect of the downwash flow field of a single-rotor UAV on droplet velocity in sugarcane plant protection. Engineering Agriculture 4: 235 – 244.
- Zhu, H., Salyani M and Fox R D. 2011. A portable scanning system for evaluation of spray deposit distribution. Computers and Electronics in Agriculture 76 (2011): 38-43.

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