In collaboration with
Adani Group

WORLD ECONOMIC FORUM

Using Technology to Improve a Billion Livelihoods

INSIGHT REPORT

OCTOBER 2022

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Foreword

The vital agriculture sector can be transformed by technology to improve food security for billions. Drones are a key enabler in this pursuit.

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The world is at an inflexion point. The economic aftermath of the COVID-19 pandemic, geopolitical tensions, soaring prices of essentials and fragmentation of global supply chains will make the next decade a turbulent one.

India, with its vast and young population, economic stability and increasingly progressive regulation can offer many insights to participants across the world to help navigate and shape the future. Technology adoption is one area where India can lead the agenda. Much has been said on the global stage about a few aspects of tech adoption in India. To name a few, data consumption, fintech payments through unified payments interface (UPI), smartphone penetration and start-up action.

However, there are truly revolutionary changes happening in the farthest reaches of the country – at the intersection of artificial intelligence (AI) and agriculture as well as between military and civilian technologies – that have the power to truly transform a billion livelihoods. Drones are at the centre of such a revolution and can become the fulcrum for a technology-led transformation of the economy.

This report, therefore, sheds light on some of the key use cases of drones emerging in India, barriers to adoption and interventions required to scale drone adoption indigenously, with a robust local supply chain. It is the result of a detailed set of interactions with various experts in agriculture, AI/tech start-ups and drone/drone component makers.

We hope that this report helps build conviction on "the art of the possible" for drone use cases and aid decision-makers in key actions and policy decisions for the future. Potential is limitless – decisive actions and cohesive work across stakeholders can help translate this potential into performance.

Executive summary

Drones can help Indian livelihoods take a quantum leap, aided by an indigenous supply chain, military-civil convergence, robust skilling and digital financing mechanisms.

Indian agriculture is going through a transformative phase where it is expected to feed a growing population while coping with the challenges of climate change, geopolitical tensions and stressed natural resources. The sector has been marred by long-term challenges such as sub-optimal yield, eroding soil health, lack of irrigation, inefficient use of inputs, lack of post-harvest management structure and access to formal financial services.

Emerging fourth industrial revolution technologies can play a role in addressing these challenges. A Ministry of Electronics and Information Technology (MeitY) report highlighted that digital tech-based agriculture can unlock further value of $65 billion by 2025. The gross domestic product (GDP) impact of digital agriculture will be even larger.

Drones are one such technology that is gaining prominence in the sector. Land mapping and agrochemical spraying are the most prominent use cases for drones in Indian agriculture. Other applications such as seeding, crop yield assessment and drone-based analytics hold significant potential. The early results have been promising. Agrochemical spraying has the potential to be actively used, considering it saves the cost of inputs by 25-90%, minimizes skin exposure by 90% and can also improve crop yield. Mapping is the second major use case with the potential to drive precision agriculture and reduce land disputes simultaneously. However, their implementation is still nascent, mainly undertaken by corporate farming institutions or large farmers.

The drone-related policy landscape for India has been eased significantly since August 2021, with enabling mechanisms like the Production Linked Incentive scheme (PLI) and import bans paving the way for the domestic manufacturing sector. However, for drones to be widely accepted as a viable mechanization option, enabling infrastructure needs to be strengthened above and beyond these policies.

It is expected that the drone and drone components industry will attract $50 billion of investment in the next few years. This flow of funds will be helpful to unlock the potential of the drone sector and make them as ubiquitous for Indian agriculture. Civil-military convergence can provide cutting-edge technologies and a better scale for the emerging drone industry. Skill development and digital finance will be foundational building blocks for the industry – creating new livelihoods and spurring entrepreneurship. These interventions need to be complemented by a robust local supply chain, standard operating procedures (SoPs) and government support especially in awareness building, safety standards and promoting drones as-a-service.

As drones emerge as a transformational innovation for the agriculture sector, there is a need to design and implement pilots at a smaller scale with clear indicators for outcome measurement, followed by rapid refinement and nationwide roll-out. If executed well, drones can help transform Indian agriculture, boost agriculture GDP by 1-1.5%, create at least 500,000 new jobs and support the country in ushering in a new digital era of prosperity.

1 Indian agriculture: backbone of economy and livelihoods

Agriculture and non-agricultural sectors have a high employment-to-output disparity for several reasons.

Snapshot of the sector

The agriculture sector is vital for the Indian economy, providing livelihood for about 58% of families and ensuring food security for 1.3 billion people.[1] Indian agriculture sector uses over 60%[2] of land and 85%[3] of freshwater resources. At the same time, it contributes to 20% of national greenhouse gas (GHG) emissions. The sector has reached a critical juncture where the challenge of food security is compounded by nutritional security, self-sufficiency, ecological problems, climate change and sharp inflation. In comparison with the industry/services sector, which adds a gross value of 80% while employing 54.4% of the country's workforce, agriculture accounts for 45.6% of the workforce at 18.29% of the gross value added (GVA) as of 2019-2020.[4]

Indian agriculture is not just significant locally but a key component of the global food supply chain as well. India exported agriculture and allied products valuing $29,815 million in 2020-21.[5] It was a growth of nearly 28% compared to the previous financial year. The main export commodities were rice, including basmati and non-basmati, sugar and cotton. On the other hand, more than half of India's agriculture imports are vegetable oil. It is expected that its import will continue to grow at 3.4% till 2030 due to rapid urbanization and dietary changes.[6] Ensuring a robust agricultural landscape in India will be important for billions of lives to prosper across the world.

2 Issues ailing Indian agriculture

A mix of infrastructural and access challenges have stopped Indian agriculture from achieving its full potential.

Nine key issues holding Indian **agriculture** back from achieving its full potential

Fragmented landholdings
Like many developing countries with large agrarian economies, India's marginal and small farmers (less than two hectares of land) own 86% of land holdings, covering 47.3% of the total cultivable area and contributing to 51% of the country's agriculture production.[7] Figure 1 indicates the approximate distribution of landholdings of five different types of farmers. With every passing generation, the land holding has continued to be further fragmented.

Inefficient usage of agriculture inputs
A critical challenge in the Indian agriculture sector is the inefficiency of production and post-harvest processes that lead to sub-optimal usage of inputs and wastages in the supply chain. Lower yield due to inefficient farming practices, use of low-yield varieties and fragmented land holding is a major impediment to farmers with higher incomes.

Low mechanization
Less than 50% mechanization adds to inefficiencies during harvest and post-harvest stages. Further, across the country, farm mechanization has increased spatially, with the highest adoption seen in three northern states: Uttar Pradesh, Punjab and Haryana (70-80% overall and 80-90% in rice and wheat).[8] This is still low, however, when compared to other countries; China has crossed 70% farm mechanization, the United States has 95% penetration and Brazil has 75% farm mechanization.

Advisory
There are currently many last-mile gaps in providing access to quality inputs and relevant advice to meaningfully support farmers. Farmers receive information from various sources, predominantly, fellow farmers (73%) and government extension (58%). Mobile service ranked fifth as a source of information out of seven (with NGOs, helplines, service providers, and media being the others) identified in a study conducted.[9]

Frequent pest attacks
Indian agriculture is prone to frequent pest attacks. In 2021-22, major pest infestations were reported in staple and cash crops, including wheat (yellow rust), maize (fall armyworm), chilli (invasive chilli

thrips) and cotton (white fly). According to a research study published in the Indian Journal of Entomology in 2015, there are 10,000 known pests that affect crops, of which 10% are considered major pests. Crop loss trends have increased in the post-green revolution era; from 7.2% in the early 1960s to 23% in the 2000s. These losses are mainly in cotton, sorghum, millets and oilseeds.[10] A recent incident in 2020 involved a locust attack that affected multiple states, including Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar. Rajasthan was the worst affected state, reporting 33% crop damage in three districts.[11]

Issues in enabling **infrastructure** compound the **problem**

Poor yield

India has a 20-28% lower yield compared to global benchmarks.[12] For example, in 2015-16, India's rice yield was 2,191 kg/hectare as compared to the global average of 3,026 kg/hectare. Similarly, wheat yield was 2,750 kg/hectare as compared to the world average of 3,289 kg/hectare.[13] Similarly, in cash crops, India's yield in cotton is 460 kg/hectare as compared to the 800 kg/hectare global average. Countries such as China, Brazil and Turkey have productivity up to 1,800 kg/hectare.[14]

Poor availability of credit and financial inclusion

Farmers require access to credit to purchase high-quality inputs to adopt efficient practices. At the same time, credit can help them gain access to post-harvest infrastructure, such as warehouses. However, in India, only 30-40% of farmers have access to institutional credit, and the remaining 70% rely on high-cost, informal sources.[15]

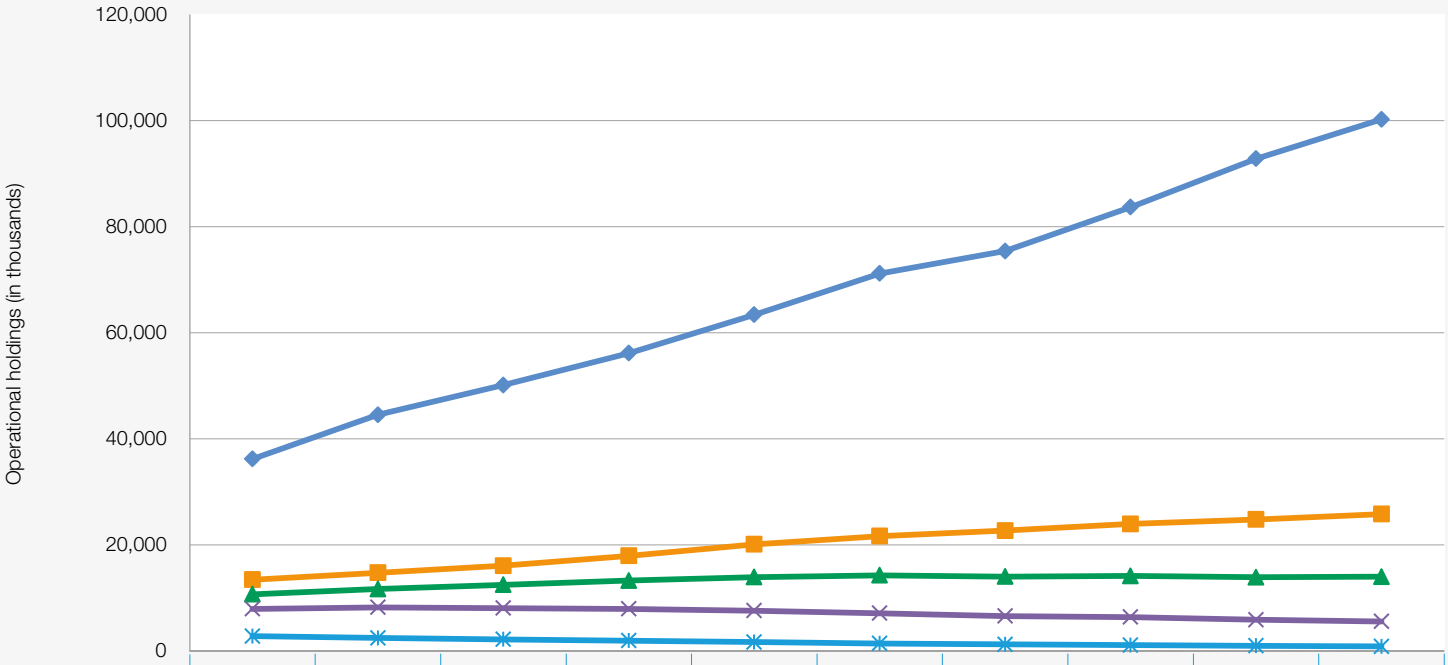
Poor post-harvest infrastructure (warehousing, cold chain)

Post-harvest infrastructure is a critical challenge to improve farmers' income and reducing the risk of food insecurity. India's crop loss due to infrastructure challenges is estimated to be between 4.5-6% in staple products, and up to 15% in perishable products.[16] Warehousing is required to store produce for sale during peak demand, however, smallholders are not the direct users of warehouses due to – among other reasons – the need to sell for quick returns to cover debt and other household expenses. Negotiable warehouse receipts to incentivize farmers to use warehouses have not been as successful as expected.

Lack of market access

Finally, in terms of access to markets, it is estimated that the country needs more than 30,000[17] additional agriculture produce market committees (APMCs) to cater to the flow of outputs. Small farmers generally rely on aggregators to collect their produce from their farm and sell it in an APMC, to avoid the additional cost of ferrying goods to an APMC or mandi, which are generally situated in block or district headquarters.

FIGURE 1 **Number of operational holdings as per agriculture censuses**



	1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
Marginal	36,200	44,523	50,122	56,147	63,389	71,179	75,408	83,694	92,826	100,251
Small	13,432	14,728	16,072	17,922	20,092	21,643	22,695	23,930	24,779	25,809
Semi-medium	10,681	11,666	12,455	13,252	13,923	14,261	14,021	14,127	13,896	13,993
Medium	7,932	8,212	8,068	7,916	7,580	7,092	6,577	6,375	5,875	5,561
Large	2,766	2,440	2,166	1,918	1,654	1,404	1,230	1,096	973	838

Source: Agriculture Census, Department of Agriculture & Farmers Welfare

3 Tech-enabled transformation with drones as a fulcrum

Drones have the potential to transform the agriculture sector and reduce disparity in the employment-to-output ratio of agricultural and non-agricultural sectors.

Potential to use technology to improve agriculture outcomes

Fourth industrial revolution technologies like AI, the internet of things (IoT), blockchain and drones are transforming the world around us. According to a report published by the Ministry of Electronics and Information Technology (MeitY),[18] digital agriculture has the potential to generate an incremental economic value of $65 billion, which represents a 23% value added to the agriculture sector by 2025.

Precision agriculture know-how and farm advisory services shared through multiple channels based on multiple existing and new data sources (soil health cards, weather data, farm/tractor-based sensors) can enable an economic opportunity of $25 billion through a 15% increase in productivity.

Similarly, there is an opportunity for about $15 billion in agricultural credit and insurance to be generated through digital interventions. These interventions use data from digitalized land records, optimal crop-cutting experiments and yield assessments through AI-based analysis of satellite images, and optimizing fertilizer direct benefit transfer (DBT), among others.

Further, there is an estimated potential for 40-60% of the agricultural surplus to be transacted through digital marketplaces by 2025 and a 10% improvement in farmers' price realization by selling produce through electronic channels, creating an opportunity of $25 billion.

Drones are poised to be an effective tool to support farmers reduce their operating costs and efforts, while at the same time optimizing their input use. There are multiple uses for drones, including surveying, seeding, spraying, pollination, etc. that are at different stages of technology and business model maturity.

Poised to benefit from civil-military convergence

Drones are one of the many military inventions that were successfully adopted for civilian applications given their dual usability. Digital cameras, duct tape, blood transfusions, ambulances and global positioning systems (GPS), to name a few, successfully made their way into the civilian space. It is therefore key that drones, given their dual utility, follow this common pathway around R&D. For global, seamless growth of the sector, with India being one of the fastest movers in terms of regulation, there is a need to manage the civil and defence frameworks cohesively.

A 2015 report, *The Taskforce on US Drone Policy*, concluded that a major fraction of UAVs were "non-weaponized" and were not a "super weapon". While they did contribute to military successes, they were largely used for tactical means, such as reconnaissance etc.[19] Thus, this presents a vast use case in civilian applications.

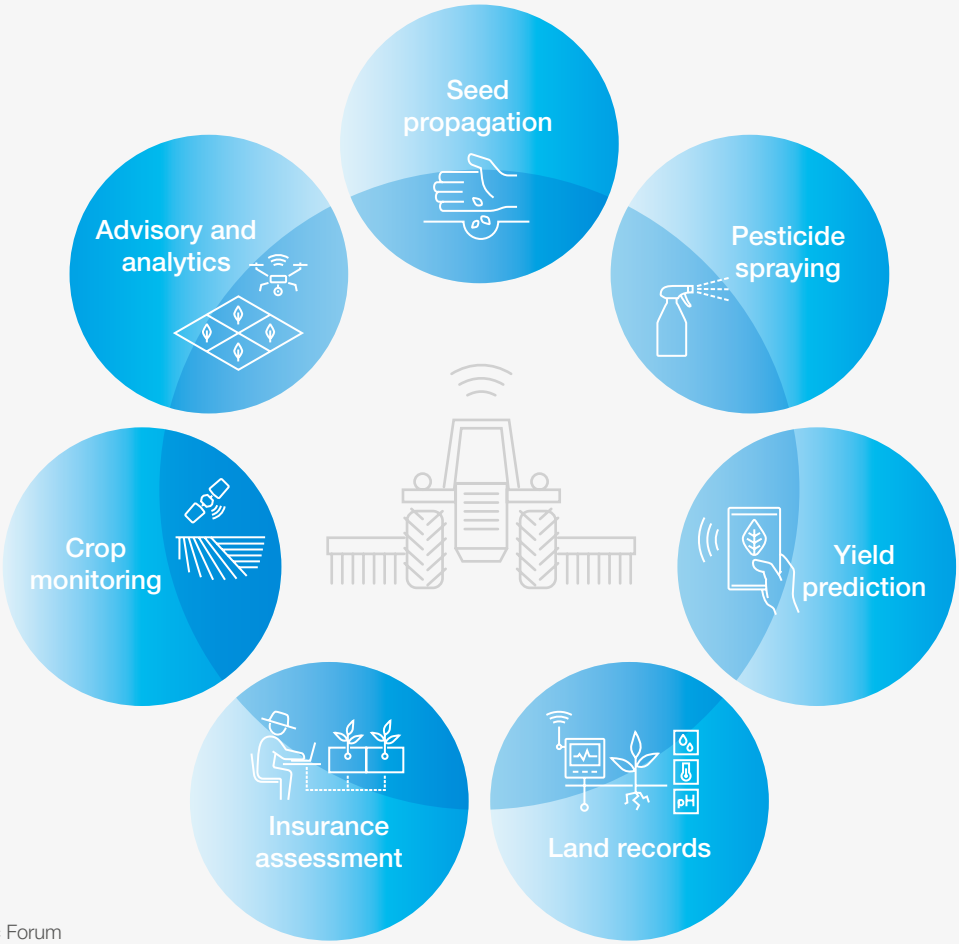
There is great potential for R&D around the form and size of survey drones. Miniaturization, for instance, not only creates a sense of operational intuitiveness but also helps cultivate the perception that smaller drones pose a lesser risk. Further, greater mobility can be achieved, thereby opening up the tech for use on a national level.

A tool to integrate digital solutions for farmer outcomes

Drones can be an effective enabler for mainstreaming different emerging technologies such as advisories, yield estimation or insurance. At a grassroots level, seeing is believing. Once drones operate and capture data for value addition or are seen efficiently spraying pesticides, farmers' trust in the technology will develop. In simple terms, drone intervention should showcase promise along with a thorough narrative that presents mitigation strategies for risks in parallel.

For example, a pest attack would be best addressed much quicker by a drone carrying pesticides than the manual approach, which has adverse health impacts for the sprayer. Farmers also receive customized advice based on data collected through drones, as opposed to generic advice that may not be relevant.

FIGURE 2 **Drones as enablers for digital agriculture**



Source: World Economic Forum

Regulatory landscape

The progressive *Drone Rules 2021*[20] have indicated a departure from earlier measures that were more industrious in nature, involving numerous forms for general clearances. In 2022, India's Ministry of Agriculture & Farmers Welfare issued a path-breaking notice to encourage the sustained use of drones in the agriculture sector as indicated below.

BOX 1

Excerpts from guidelines issued by India's Ministry of Agriculture for small and medium land holding farmers to procure drones and drone services

Depending on the requirements, farm machinery training and testing institutes (FMTTIs), Indian Council of Agricultural Research (ICAR) institutions, Krishi Vigyan Kendras (KVKs) and state agricultural universities (SAUs) will be provided financial assistance (100% grant in aid) for purchase of agricultural drones and its attachments (actual cost of an agricultural drone and its attachments or INR 1 million (Indian rupee), whichever is lower) for conducting demonstrations on the farmers' fields.

Farmer producer organizations (FPOs) will be provided with a 75% grant-in-aid for the purchase of agricultural drones and their attachments for conducting demonstrations on the farmers' fields.

The proposals for the purchase of drones and their attachments will be submitted by the implementing agencies and will be considered by the executive committee of the scheme for allocation of funds.

Implementing agencies that do not wish to purchase agricultural drones for demonstration, can hire the drones to be demonstrated from hubs/manufacturers/start-ups. In such cases, the department will provide 100% assistance at a rate of INR 6,000 per hectare to meet contingency expenditures, such as charges towards hiring of drones/drone pilots, Expenditure towards hands-on training and miscellaneous expenditure, such as transport, labour, publicity and printing of technical literature etc.

The rate of grant to meet the contingent expenditure will be INR 3,000 per hectare in the case of the implementing agencies that will be provided grants for the purchase of agricultural drones for demonstration.

Source: Ministry of Agriculture & Farmers Welfare

These guidelines act as a force multiplier to two key reforms by the central government: firstly, the Production Linked Incentive (PLI) scheme[21] issued in 2021 incentivizes the production of drones and drone components indigenously for a period of three years. Secondly, the "Drone Shakti" announcement in the Union Budget 2022 promotes the use of drones as-a-service.

FIGURE 3

National drone programmes and policies

Drones Rules 2021

Ease of operations given that most of the country is in a "green zone".

Reduced number of forms to "street legalize" drones.

Sub-mission on agricultural mechanization

Financial assistance to farmers/agencies, who want to purchase or procure drones as-a-service.

PLI scheme

Encourage indigenous manufacturing of drones and drone components for three years while banning imports to give local companies a head start.

Drone Shakti

Budget announcement promotes drones as-a-service across the country.

Notification on amendment of SCOMET list

Promotion of exports of India-made drones and Indian service providers.

Source: World Economic Forum

Use cases and promising case studies
Based on the specifics of the use cases, sensors mounted on drones are of several different types – RGB, thermal, multispectral, light detecting and ranging (LiDAR). Drone image processing is invariably required for the following use cases:

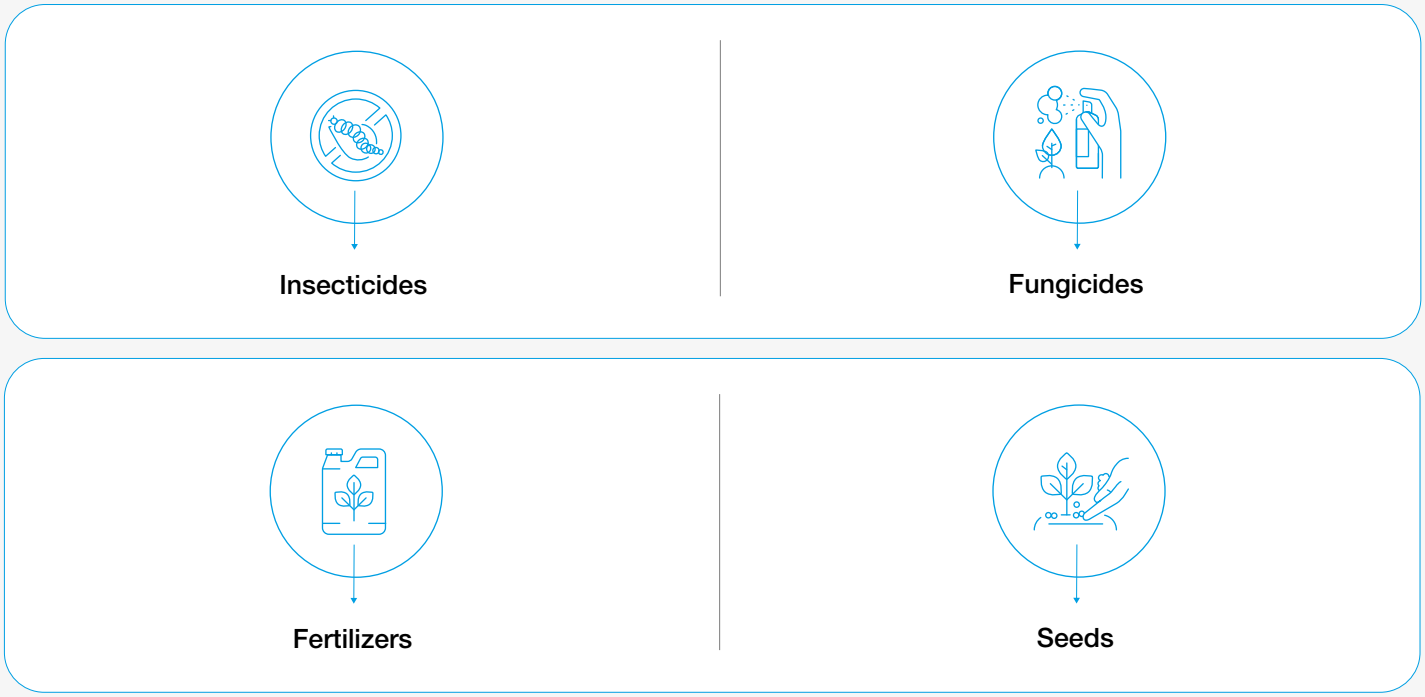
1. Precision farming, such as determining the degree of weeds for site-specific herbicide applications.

2. Biomasses and crop growth monitoring and health assessment.

Use case: Precision farming – inputs application
Drone spraying is a specialized yet practical method to address several economic factors. Firstly, due to the uniformity and precision of spraying, fewer areas are left out in comparison with conventional methods, leading to greater yield. Secondly, when coupled with drone mapping to identify specifically distressed areas on the field, spraying of pesticides or fertilizers can be optimized. In other words, there would be no need to spray in unwanted areas, leading to a 15-20% increase in income. Lastly, the concentration of the active ingredient can be increased specifically for affected areas. Underdosing the mixture may lead to resistance in pests. Overall, a yield increase of 15-20% may be observed. When the practice is scaled up, operational costs tend to diminish, thereby reducing the production cost of the crops. The mapping-spraying combination using drones can save pesticides by up to 90%.

Spraying is a prominent use case for drones in the Indian agriculture sector. In May 2022, the Ministry of Agriculture & Farmer Welfare issued a two-year approval for spraying of 477 formulations containing single as well as multiple active ingredients.[22] This is a breakthrough in scaling drone-based spraying in the country.

FIGURE 4 **Spraying and broadcasting applications**



Source: World Economic Forum

Superiority against traditional spraying methods

When comparing conventional and drone-based spraying, the chemical recommendation of pesticides remains the same since any change in the active ingredient can create resistance in pests and insects. In terms of efficiency, however, drone spraying is more uniform and precise than conventional methods. Further, if drone spraying is planned based on mapping data, pesticide use can be reduced by up to 90% compared to the conventional method. Drone-based spraying is also effective for pests that spread at a faster speed. Drone spraying can effectively contain the spread by covering the field in 2-3 hours compared to the 2-3 days required for manual spraying. In terms of operational costs, drone spraying addresses a critical issue of labour shortage in agriculture. Manual spraying generally costs, INR 650-1,000 per acre per day and it would take 2-3 days to cover a farm of one hectare. The same farm can be sprayed by drones in five to six hours, saving up to a quarter of the cost of manual spraying. Different studies have highlighted that drone-based spraying could reduce input usage by 30-50%.[23] In terms of yield increase, there are no definitive answers, but experts predict it to be in the wide range of 10-15% based on the crop and the land size.

Reduced accidents

Drone-based spraying also has health advantages, mainly for drone operators. When compared to the three stages of spraying, sprayers' contact with chemicals remains the same, as the sprayer mixes and puts the concentration in the tank. However, dermal contact during drone spraying is reduced by 90-95%, due to the distance between the operator and the spraying machine. The contact is almost the same during the post-spray stage. Precision spraying from drones also reduces chemical penetration or seepage in water bodies.

In terms of the risks, phytotoxicity effects in drone-based spraying needs further study. Improper dosage when using drones can lead to higher concentrations of chemicals, potentially causing higher phytotoxicity when compared to the conventional methods.

Further, it is likely that drones may also be used for blanket spraying rather than precision spraying. To avoid this situation, FPOs should have access to agronomists for technical advice regarding the frequency and span of spraying.

Success story: Drone spraying in cumin crop

GOAL

- Studying how the cumin crop reponds to agricultural drone spraying to understand the overall benefits of the technology. Case study by Adani General Aeronautics (Adani GA).

CHALLENGES

- India is one of the major producers of cumin attributing to around 60-70% of the world's produce.
- The crop is soft and fragile. Hence farmers refrain from entering the field once production starts.
- Hand broadcasted agrochemicals result in water wastage and therefore increased input costs.
- A significant portion of cumin exports get rejected due to high pesticide residue levels (maximum residue levels (MRLs)).

SOLUTIONS

- Cumin farm of 2-acre size was selected to conduct this experiment in western part of India. A combination of pesticide was sprayed using Adani GA agricultural drone. The experiment was conducted with controlled droplet size using variable rate nozzle system.
- In order to ensure uniform application of pesticide on crops, it is essential to carry out a marked spray mission to avoid multiple passes – leading to excessive use of agrochemicals, which often results in phytotoxicity.
- Drones enable precise positioning and marking for the sprayer, resulting in minimum overlap between each pass, and have the potential to complete its mission near around the field edges that would be missed in conventional methods
- Usually the sprayer takes two hours to cover just 1 acre of farmland with a manual cost involved in this whole procedure, while the drone takes just 12-15 minutes to cover that same acre of land, thus could cover up to 60 acres of land per day.

CONCLUSION

- Drone technology and the use of its UAVs in such applications has brought about multiple benefits, saving time and cost envisaging huge potential in increasing farmer's income. With every advancement these spray drones will be one of the most advantageous equipments for modern agriculture. They have demonstrated overall much better spray-efficiency and yield, reducing wastage of natural resources at the same time compared to various conventional methods. Drones can be a critical element in the protection of the environment and labour.

Source: "Spraying Agrochemicals using GA spray drones to achieve controlled MRL (MAXIMUM RESIDUE LEVEL) in Cumin seeds", *General Aeronautics*, 6 September 2021, https://u2m.25b.myftpupload.com/spraying-agrochemicals-using-ga-spray-drones-to-achieve-controlled-mrl-maximum-residue-level-in-cumin-seeds/.

Success story: Yield improvement and cost reduction in sugarcane crop

GOAL

- Yield improvement and cost reduction through drone-based spraying in sugarcane crops. Case study of Prateek Patil and Rajarambapu Sugar Factory, Sangli, Maharashtra, India.

CHALLENGES

- Knapsack-based spraying is costly: approximately INR 1,000 per acre in labour costs.
- Requires 4-5 hours to spray on 1 acre through knapsack spraying.
- Lack of labour witenssed during COVID-19.

SOLUTIONS

- Prateek Patil, as lead farmer, conducted 22 community meetings with 4,900 farmers to seed the idea of using drones for spraying in sugarcane fields,
- He partnered with a regional drone manufacturing company. A drone was rented at an affordable price, saving approximatley 40% of the typical cost.
- Only 5-10 minutes were required to spray fertilizer and pesticides on a 1 acre farm.
- The cost of fertilizer and pesticides was reduced by 25-30%.
- A yield increase of 20-30% was reported.
- By October 2021, 3,200 acres of area were covered by drone spraying, benefiting more than 2,000 farmers in the region.

CONCLUSION

- Drone-based spraying reduced cost of cultivation and efforts required.
- Improvement in yields were reported, especially in cash crops that required frequent spraying.

Source: "Drone Spraying in Sangli Sugarcane Cultivation, social impact entrepreneur introduces new trends in MH Agriculture", *Auto.com, The Economic Times*, 25 October 2021, https://auto.economictimes.indiatimes.com/news/auto-technology/drone-spraying-in-sangli-sugarcane-cultivation-social-impact-entrepreneur-introduces-new-trends-in-mh-agriculture/87255728.

Success story: Phytotoxicity reduction in potato crop

GOAL

- Crop management (pesticide spray) using drones for a potato crop.

CHALLENGES

- Potato crops are susceptible to large numbers of insect-pests and diseases.
- To achieve high productivity in the span of 90-110 days, regular application of pesticides is recommended.

SOLUTIONS

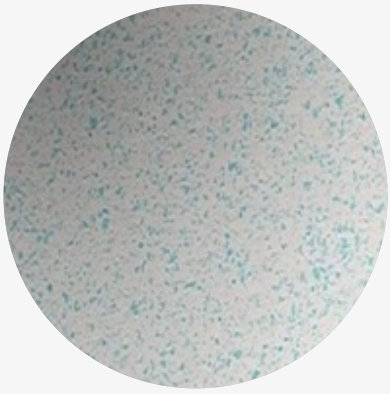
- Drones were used for pesticide application.
- Recommended doses of pesticides were tested in ultra low volume of water for phytotoxicity, uniformity of spray and possible drift.
- Drones with 20-litre storage tanks and four centrifugal atomizing nozzles were used.
- Drones were flown at 12.6 km/hour with flow rate of 60 litres/hectare at an altitude of 2 metres.
- In the first year of testing, eight pesticides were tested and none of them exhibited phytotoxicity, similar results were recorded for 14 pesticides in the second year.
- There was uniform and better penetration with finer droplet coverage as compared to knapsack spraying.

CONCLUSION

- Drone-based pesticide spraying ensures uniformity of spray, better penetration and no reported phytotoxicity.
- Further experiments are required to build on this promising use case.

Source: "Drone Based Potato Crop Management Technologies", ICAR.

FIGURE 5 | **Spray droplet distribution**



Spray droplet distribution within treatment

Spray droplet distribution in buffer zone

Source: "Drone Based Potato Crop Management Technologies", ICAR

Use case: Biomasses and crop growth monitoring and health assessment

A drone service provider may approach the problem as a plant protection doctor. This would entail certification in not just drone operations but also basic agronomy. Symptoms of issues that riddle crops such as rust, smut, mould and other diseases may be captured through aerial surveys in order to train data sets accordingly. As the library of signature data increases, the probability of identifying the disease as symptoms arise increases, as does the chance of administering the correct solution. Hence, an agricultural drone service provider requires an interdisciplinary skillset not limited to pure-play drone operations.

FIGURE 6 **List of drone-mounted sensors for survey**

Sensor	Features used	Advantages
Visible (RGB) camera	Colour, size, shape, edges, surface	– Easy to identify by visual inspection – Cheap and small in size – Small payload for unmanned aerial vehicle (UAV) – High resolution camera – Easier to use
Multispectral camera	Appearance and geometrical features, normalized difference vegetation index (NVDI)	– Images in more spectrum bands than the red green and blue (RGB) can be captured – More information than an RGB digital image – Captures spectral bands near infrared (NIR) – Provide information about reflectance of visible light and vegetation indices
Hyper spectral camera	RVI and NDVI indices	– Creates images using thousands of narrow bands – Multidimensional datasets – Can detect more features than multispectral camera – Acquires entire at each point
Thermal camera	Crop water stress index (CWSI)	– Have greater spectral and spatial resolutions – Quick determination of canopy surface temperature – Small size – Low weight

Source: Hafeez, Abdul, Muhammed Aslam Husain, S. P. Singh et al., "Implementation of drone technology for farm monitoring & pesticide spraying: A review", *Information Processing in Agriculture*, vol. 9, no. 3, 15 February 2022, https://doi.org/10.1016/j.inpa.2022.02.002.

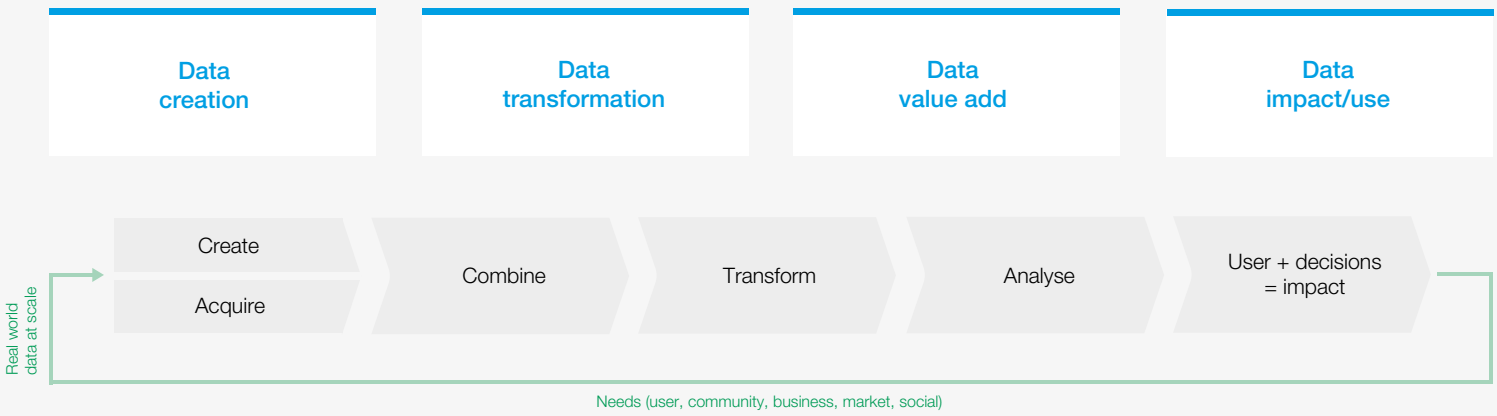
Farm monitoring is critical to ensure the supervision of emerging risks of pest infestation and visual checks on critical parameters, such as soil moisture or plant health. While smallholder farmers can carry out this exercise easily, it is a time- and resource-consuming task for medium and large farmers. In both cases, the assessment is subjective or relies on further analysis by third parties, such as soil testing or pest infestation.

Drone-enabled surveying coupled with AI analytics can provide informed advisories and courses of action to farmers. In such a survey, drones coupled with cameras and sensors can help reduce farmers' efforts. Figure 6 represents the range of sensors that can be used for spatial insights in a host of use cases.

Surveying is most effective in highly-priced commodities or crops, large farms and high-height plants, such as corn or sugarcane, where it is tough to do a manual survey after the gestation period.

Specific to advisories based on surveys, AI algorithms improve with incoming data from each season, so near 100% accuracy cannot be expected in the first year. Generally, it would take 2-4 cropping seasons for algorithms to improve to 70%-plus accuracy. Thus, in the drone surveying use case, two aspects need to be urgently addressed to scale up adoption: setting farmers' expectations regarding result accuracy and expectations on turnaround time in the sharing of results.

FIGURE 7 **The drone data value chain**



Source: "Understanding Data Sharing – the Data Value Chain", Icebreaker One, n.d., https://icebreakerone.org/understanding-data-sharing-the-data-value-chain/.

BOX 2 **Combating locust attacks**

In 2020, the local administration in Jaipur used drones to quell frequent locust attacks in the Chomu district. The attack spread over 1,000 hectares impacting 12 villages. The Locust Warning Organization endorsed the measure as impactful and cost-effective as drones could fly above locust swarms, enabling an overhead strike. Ten-litre pesticide tanks were docked to drones for the spraying exercise. These tanks were exhausted in 10 minutes and refilled using tractors. This improved flexibility significantly and enabled applications in areas that were very difficult to reach.

Source: CGTN America, "Drones combat locusts in India", *YouTube*, 2 July 2020, https://www.youtube.com/watch?v=T1TbDGlqS4E.

Success story: Detection of pest infestation in coconut crops

GOAL

- Identifying pest infestation and assessing plant health in coconut plantation.

CHALLENGES

- Pest infestation is common in coconut crops and is challenging to detect due to the height of the tree and complexities in identification.

SOLUTIONS

- As per a 2019 study published in the Journal of Artificial Intelligence and Capsule Network, deep learning was used to identify pest infestation in coconut trees.
- In the study, Adani GA drones were used to capture the tree images. The drone was embedded with a digital camera.
- Images captured through drones built the database and images were annotated by experts. The pictures were further segmented into pixels that helped identify tree's health based on colour information.

CONCLUSION

- The solution was able to detect five pest attacks and four diseases.

Source: Chandy, Abraham, "Pest Infestation Identification in Coconut Trees Using Deep Learning", *Journal of Artificial Intelligence and Capsule Networks*, vol. 1, no. 1, 2019.

4 Drone potential can be unlocked with the right enabling landscape

Sustainable market systems must be created in order for drone adoption to scale in agriculture.

The farmer needs solutions

The main concern of the average farmer is the quantity of farm output. A drone service provider must be able to deliver incremental value through higher outputs. Further, more than a mere diagnosis of a problem through visual inspections, the farmer seeks solutions to the issues at hand. Hence, surveying, mapping and analytics need to be coupled with spraying applications to alleviate the issues on the ground.

It is clear from the case studies that drones can create significant impact for the farmer. Agriculture is poised to benefit significantly from the adoption of drones; however, achieving this impact will require a cohesive effort across the entire industry. Figure 7 indicates the key parts of the agriculture value chain that need to be jump-started to drive adoption.

Institutions such as FPOs, custom hiring centres, state agricultural universities and KVKs (farmer development centres) need to play an active role in educating farmers about the merits of the technology.

FIGURE 8 | The business canvas for drones

*Original equipment manufacturer
Source: World Economic Forum

Component economy

For drone services to thrive in India, the country needs a national level streamlining of production systems and production capacity, and rapid cycle manufacturing. For this, it is important to know about drone components and their availability, source and potential to manufacture in India, not only to address gaps in the supply chain but also to indigenize manufacturing in alignment with the "Make in India" agenda. Components such as batteries, brushless direct current motors (BLDC) and key avionics, such as flight controllers, must be manufactured locally. Components of high value, such as LiDAR sensors and autopilot, must be on the planning horizon.

India has approximately 593,615 inhabited villages, all of which have a reasonable level of agricultural activity.[24] For drones to address such a high input level, India needs to ramp up production capacity.

Productivity in agriculture is determined largely by the inputs used by farmers at the time of cultivation. Further, several studies have indicated that the "per hectare" output of a mechanized farm is higher than that of a non-mechanized, irrigated farm.[25] The case for the integration of drones into the grassroots agrarian system should be a top priority, given the potential of the technology and the mileage that drones have obtained in the agricultural sector globally. For example, rice fields are drone-enabled in Japan through aerial imaging and spraying. Given that rice is a critical agricultural product for the country, drones are being used to survey crops and identify pests, mould and other diseases. Close to 50 pest varieties can now be eliminated by spraying pesticides remotely. The drone-based solution also addresses the country's labour shortage.

Facilitate access to capital

Drawing a parallel with the onset of farm mechanization through tractors in India in the mid-20th century, the high capital cost of equipment leads to concerns about the financial sustainability and application by smallholding farmers, who represent a sizeable majority in India.[26] Through policy support and shared models, however, tractors are now accessible to all classes of farmers. Input Census data (2011-2012) suggests that 44% of smallholding farmers (less than 2 hectares of land) use farm machinery.[27] Drones may follow a similar trajectory in the adoption cycle.

Liberalized regulations have largely been a precursor to a high level of economic activity in the agricultural sector. In the case of drones, the regime has been significantly liberalized through the *Drone Rules 2021*. Further, one of the first "type certified" drones in India is specifically agriculture centred. However, as per India's export policy, UAS are dual use and hence prohibited or licenced under the special chemicals, organisms, materials, equipment and technologies (SCOMET) nomenclature. This adds to the burden for MSMEs that manufacture RPAS for civilian use cases, including agricultural applications.

Drone owners and operators would require access to commercial finance as capital to purchase the drones and secondly as working capital finance to fund operations considering the "machines-as-a-service" model is generally based on credit and staggered payments by farmers. Concentrated efforts are needed from regulators, non-banking financial corporations (NBFC), banks and drone manufacturers to develop customized financial products, risk assessment structures and risk mitigation mechanisms to mainstream commercial lending for drones under priority sector lending (PSL) targets. The Ministry of Civil Aviation's "DigitalSky" portal allows for the registration of drones and type certifies them. This data coupled with other data sets can be used for tech-enabled digital lending to drone operators.

Education and awareness

Networks of KVKs and other government last mile resources can be used to create trust in drones, or as a trigger point while word of mouth and peer-learning picks up. Demonstration will be a critical activity to be carried out by these channels. Panchayat and local elected representatives, such as a Sarpanch, can play a critical role in incepting the concept of drones and promoting their usage.

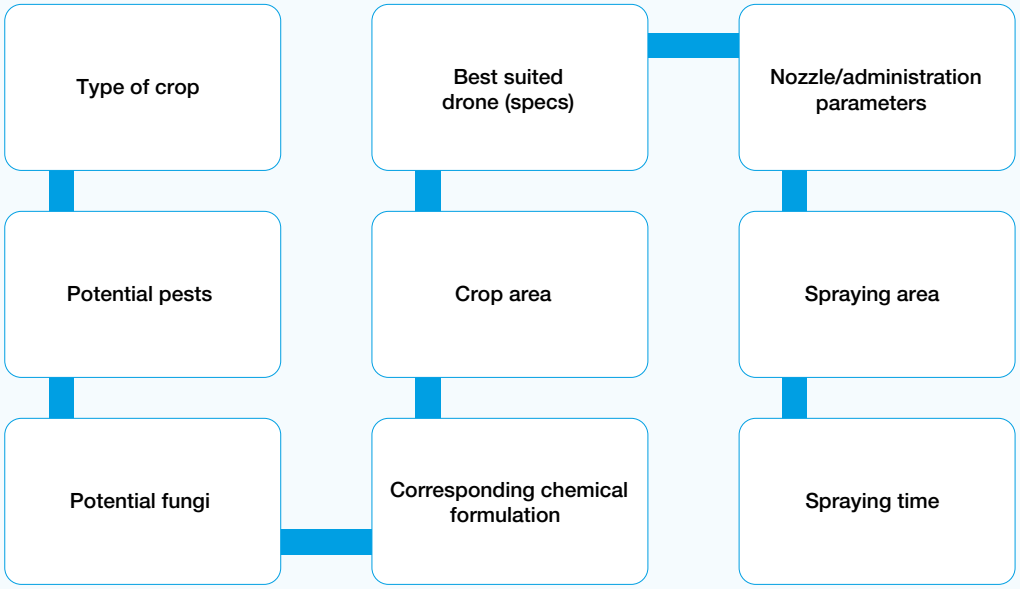
Agriculture universities, ICAR or KVKs, should support drone operators to develop standard operating procedures (SoPs) for each use and crop. These institutions can also support drone operators in validating the SoP in the experiment field. Box 3 outlines some key aspects of adoption in the context of spraying services that need to be disseminated by institutes such as KVKs and Indian Council for Agricultural Research.

BOX 3 | **Need for protection mechanisms for drone spraying**

As drone adoption increases, a parallel protection mechanism must evolve to ensure damage is averted or even indemnified. For instance, if spurious chemicals are supplied to the farmer, they are tested based on which fines are levied on the supplier. Similarly, an operational framework for drone spraying that protects the farmer may further increase the adoption of drones. Checks and balances on an unbundled suite of drone-centred solutions would increase confidence levels across the spectrum. For example, once the right proportion of chemicals is accepted, spraying using drones must be a thorough exercise using well-defined specifications of drone endurance and spraying velocity. Administering the incorrect chemical, overdosing or underdosing may result in long-lasting damage. A few pre-operational questions may be:

1. What crops are in the scope of the exercise?
2. What is the best possible method to alleviate the problem at hand?
3. What is the formulation of pesticide/fungicide?
4. What time of the day does the drone operator need to administer the chemical?
5. Are there any seasonal considerations? For example, several beneficial organisms may approach the crop during the pollination season. Will they be affected by the spraying?

FIGURE 9 | **Decision criteria for the use of spraying drone**



Source: World Economic Forum

Post-sales service

Post-sales service is critical to ensure the sustained use of drones. The drone spraying market urgently needs a validation study over an extended period to ascertain longevity. For example, a capital investment of INR 1.4 million for a spraying drone may be equated with purchasing a small SUV in India. The vehicle, however, arrives with certified components, post-purchase service contracts, insurance and other customer-centred terms. The same level of service is yet to be established for spraying drones, largely due to the maturity of the component supply chain. For instance, if, after 100 drone sorties, batteries begin to fail suddenly, the impact could be disastrous, as a highly capital intensive tool would have to be written off. Considering drones will be mainly used in agriculture in rural areas, the drone providers must innovate on creating local cost-effective post-sales service infrastructure. This stands true for both service and spare part availability. Skilling youth in cooperation with industry in vocational training institutions on drones' maintenance and post-sales service can be an initial step to creating the infrastructure.

Skilling

Further, the "metro-to-rural" model needs a tectonic shift. Start-ups based in metropolises cannot travel to rural areas for extended periods to provide their services. There needs to be a gradual handover to rural youth. Local agricultural universities/students could act as an effective middle ground in this process.

The lack of trained operators is a challenge for many large agricultural machines. For example, harvester operators from Punjab are highly sought after across the country. As the drone market develops, there will be an increased demand for trained drone operators. Educated rural youth, agriculture polytechnic graduates and information technology institute (ITI) graduates can be considered to create this workforce.

The government of India has already announced plans to induct drone-related courses in ITIs. Considering mapping and surveying would require specific knowledge about pests and their management, the government can also establish a certificate in pest formulation and spraying. Applications such as the iKhedut application can be helpful to educate youth about drones and the courses.

Original equipment manufacturer (OEM) environment

In terms of flying, drone companies should standardize the process of flying drones by providing a pre-flight checklist (such as checking for cracks, battery charge, etc.) and come up with OEM manuals for operating drones. The training module should also include an introduction to software components based on the region, taking into consideration the diversity of crops, pests and infestations, pesticides, spraying timelines etc.

A few interesting observations can be noted during the developmental and adoption cycle of farm machinery, which may help to trace the trajectory of drones. Firstly, during the green revolution era (1961-1997), statutory price controls on tractors were withdrawn (October 1974). The 1980s saw India become a net exporter of tractors. Secondly, in 1992, government approval for manufacturing and licencing tractors was abolished. Soon, in 1997, Mahindra & Mahindra became the largest tractor producer; more than two million tractors were in use by this time.[28] Currently, small- and medium-holding farmers also own tractors. They in turn hire out their tractors for agricultural and non-agricultural purposes, thereby encouraging entrepreneurship at the grassroots level. Schemes, such as the PLI scheme for drones and drone component makers, are a useful tool to encourage entrepreneurship and should be persisted with. Additionally, drone parks, centered around OEMs, can be set up to ensure cluster-based development and promote vibrant adoption.

Government support and advisory

A drones-as-service model should be based on regional requirements and must be built in advance of market demand.

The government has already taken an enabling decision by promoting "Made in India" drones. This will strengthen the industry. However, to cater to the vast market and its needs, the government should create a big picture point of view on the drone manufacturing industry for the next ten years. This would require a detailed analysis of the ancillary industries and their supply chains to ensure the continued supply of different drone components for the manufacturers.

Drones are gaining trust as a problem-solving technology and demand-side incentives would help drive its uptake. Integrating a government advisory programme with drone applications for surveying will help farmers receive localized advice. Such an integration will encourage farmers to move towards precision agriculture and at the same time promote drones as an effective data collection tool.

Service delivery: Drones-as-a-service

Assuming that India's 593,615 inhabited villages would be supported by a drone and a supplementary team of rural youth to operate the drones, the value chain of the drone services includes training academies or remote pilot training organizations (RPTOs) coupled with agronomical insights to meet the demands of the Indian farmer. While farmers are the direct beneficiaries of drone technology, the responsibility of enablement falls upon local governments and state departments. To align with the three simple decision criteria at the grassroots level (risk, cost and profit), it is key to have a cooperative approach where a technologically informed "society" can demystify drones and alleviate concern around technology integration.

The drones-as-a-service concept can mainstream its usage in line with conventional agriculture machines, such as tractors or harvesters. In India, tractors are widely used by farmers "as-a-service", whereby roughly 7 million tractor owners serve the remaining farmers. A possible business model for drones can be defined on the following parameters:

User profile

The profile of a drone user is not based on the land holding. Drones could be more useful for smallholders, compared to large farms. With drones' operating time of 20-30 minutes, spraying can be done much faster than manual spraying, which could take 1-2 days for a smallholder.

As of today, the class of drones best suited for surveying, mapping and spraying fall under the "small" category of drones (2-25 kg) as per India's drone policy. With an average endurance of 20 to 30 minutes, smallholding farmers may be ideally suited for drone spraying services (including rental or pooled services). Smallholding farmers may not have the capacity to purchase drones outright or even operate and service drones if obtained through subsidy schemes. Hence, the service model would be ideal to cater to all classes of farmers, especially smallholding farmers.

FIGURE 10 **Key elements of drone integration for validation studies**

Education	Reliability	Reduction in input costs	Crop selection for pilots
– An agro-aeronautical curriculum for service providers – Correct messaging by grassroot agencies to enhance the farmer's understanding	– Reality check on the technology maturity to cater to every village in India – Arriving at the life span of the drone and it's total cost of ownership especially in spraying	– The cost of arriving at a decision on farm input cannot be greater than the production cost e.g cost of spraying per acre per pass should be subsidised	– Cash crops may serve as a useful starting point to run a drone vs no drone pilot

Source: World Economic Forum

Ownership
Ownership of drones could be divided into two categories:

- **Private ownership:** Like tractors, this model would focus on drones' strengths to drive its purchase by lead farmers who own more than 10 acres of land. This approach may require more time for the market to evolve. However, it would be a sustainable approach driven by business propositions. This approach can be compared to the Uber or Ola model, where assets are privately owned and rented as-a-service on a "pay as you go" basis.

- **Community ownership:** Considering the existing perceived high cost of drones and their limited adoption, FPOs/cooperatives can own the drones and share them with farmer members as-a-service. This model would be backed by government or state institutions through grants or subsidies. Ownership of drones by FPOs/cooperatives will help shorten the time required to create trust in the machine and its proposition; however, this would limit its uptake as a mechanization product for retail customers.

It may take three to five years for markets to mature. Market maturity and uptake will increase as drones become cheaper with an expanded after-sales service network. Further, like conventional agriculture machinery, with the passage of time and use experience, drones may gain acceptance as a multi-utility machine creating cross-revenue opportunities for owners, ensuring low downtime and high returns on investment (ROI).

Drones-as-a-service models should be based on regional requirements. There are approximately 600,000 villages in India. The manufacturing supply chain, drone services and training organizations need to ramp up swiftly to cater to this requirement if every village is to become drone enabled.

5

Role of stakeholders in scaling up drone adoption

Nine key stakeholders need to act in cohesion to make mass drone adoption a reality.

FIGURE 11 **Stakeholder map**

- Farmer producer organizations
- Agricultural universities
- Krishi Vikas Kendras (KVKs)
- Financial service providers
- Village panchayats
- State agriculture department
- Central government
- Indigenous manufacturers
- Service providers

Source: World Economic Forum

Creating drones-as-a-service would require multistakeholder collaboration. The following are proposed building blocks:

FPOs
As an aggregator, FPOs have a member base ranging from 100-1,000 farmers. These FPOs are fast gaining acceptance as a stable channel for delivery of different services to farmers as they have mass outreach and enjoy the farmers' trust. For greater drone adoption, FPOs can play two key roles:

1. Act as a channel of awareness.

2. Rent out owned drones as-a-service to members.

FPOs may get subsidies or loans from the government to purchase drones. In many instances, access to technology would not mean active use. The same risk stands in this case, where FPOs may purchase a drone but lack a business model. They need first to build their capacity and establish a business model.

Agriculture universities
State agriculture universities should create use case testing environments on campuses to create SoPs for drone spraying of the state's prominent crops. They should also run training courses for lead farmers to learn about drones and drive their adoption. Universities can be a source of trained, skilled workforce to operate drones or create courses specific to drone operation certification.

Krishi Vikas Kendra (KVKs)
Awareness building is an important factor to be considered. Krishi Vikas Kendras can run training and awareness sessions or workshops for farmers. Their training also provides the seal of trust for new technologies.

Village panchayat
The government of India is working on the Smart Village Panchayat initiative, which can be used to promote drones. Panchayats should provide administrative and coordination support to drone operators to establish their operations in their respective panchayats. Panchayats should also run awareness or peer learning for farmers.

State agriculture department
State agriculture departments should act as the nodal coordinating agency to promote drones in the state. Agriculture departments can chalk out a plan to introduce drones in a staggered manner while ensuring the necessary ingredients are in place and actively working to scale, operate and maintain drones. Departments can create a core group of department officials, state agriculture universities, National Bank for Agriculture and Rural Development (NABARD) or other financial institutions and panchayats.

Financial service providers
Financial service providers need to quickly customize offerings keeping in mind the specificity of drone technology, e.g. rapid evolution, quick replacement of parts, rollout based on ground situations, etc.

A drone operator, be it an individual or an FPO, requires access to financial services for:

– Credit for the purchase of drones. This would require establishing the drone as an asset and defining its resale or scrap value to be established in the books of the banks.

– Working capital to sustain drone operations; in many cases, this would be a credit-based service.

– Insurance for drones considering the risks associated with flying and the high cost of spare parts.

Village Level Entrepreneurs
Village Level Entrepreneurs (VLEs) will be responsible for operating the drones as per the OEM and standard procedures. They will also be critical to maintaining drones to operational conditions. Having rural youth trained as VLEs will increase farmers' trust in drones.

Central government
While the key beneficiaries of drone technology are at the state and district level, the central government would take a lead role in powering up the drone economy. As India's apex think tank National Institution for Transforming India (NITI) Aayog would provide thought leadership and insights into promoting drones in farm mechanization initiatives through its various programmes. Drone reforms by the Ministry of Civil Aviation have made most of India's low altitude and green zone status. However, rapid tech advancements require constant oversight to ensure drone operations are safe and secure at all times. Agricultural drone applications present vast amounts of data that can support evidence-based policy-making.

Indigenous manufacturers/service providers
An enabling environment is needed for indigenous manufacturing, including ancillary industries for drone manufacturing. It is important that quality, standards and services are of a high standard and competitive with world markets. Establishing standards on component interoperability and service delivery across service providers and manufacturers will help provide the much needed statistics to facilitate meaningful iterations.

Conclusion and next steps: Creating a microcosm for drone adoption

At the Drone Festival of India 2022 on 27th May in New Delhi, India's Prime Minister, Narendra Modi, stated in his keynote speech, "Promotion of drone technology is another medium of advancing our commitment to good governance and ease of living. In the form of drones, we have a smart tool that is going to be part and parcel of people's lives".[29] He has clearly highlighted the country's intent to ensure that drones become a common tool at the grassroots level. In pursuit of this vision, the policy reforms highlighted earlier in the report have increased confidence in drone technology. However, to reap dividends from drones both operationally and economically, all stakeholders will have to work together to embark on a model that optimizes short-term gains while creating value for society in the long term. For this, the needs of all stakeholders must be accounted for.

Considering the complexity of the agriculture sector and the greenfield nature of drones-as-a-service, governments (central and state) should create lighthouse applications and pull in the right set of investors and stakeholders as mentioned in Figure 11. Such a lighthouse application may be defined on the following parameters:

Scope: Define the scope of the drone operations based on four dimensions: 1) specific location, 2) use case to be implemented (the limited scope will help define measurable outcomes for the intervention), and 3) timeline.

Multistakeholder core team
Drone operation requires multiple partners. Key actors will also vary depending on the nature of the use case and service rendered. The nodal agency should be well defined for each of these use cases.

Rule of engagement
Departments should also define rules of engagement for different parties in the drone value chain. These rules will define how the government will enable the landscape (data, resources, finances, etc.) and what the expected role and outcome for each party will be.

Indicators
An engagement success indicator should be well-defined in advance. This would help in documenting baseline outcomes and impacts in long run.

Education
There is an urgent need to communicate the benefits of drones to the grassroots level and to ensure that the drone service provider is actually addressing the knowledge gap on the ground. This would demand specializations in mobilizing hardware and in agronomy.

A well-orchestrated drone ecosystem, driven by support from the government and other key stakeholders can truly establish the "art of the possible" for a drone-led transformation of agriculture. This transformation can generate 500,000 jobs in the sector in the next three years[30,31] and improve agriculture GDP by 1-1.5%.[32]

The success stories that come from this effort will rapidly fuel the next wave of growth and make the immense potential of India's agriculture transformation a reality.

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