Week 3

Drones, Robotics, and Automation in Agriculture

Session 3(Week 3)

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A comparative analysis of adoption models, policies, and use-cases in India and the United States.

Aim · By the end of this lecture, you will be able to contrast high-scale tractor autonomy in the US with service-based spray drones in India, understanding the understanding the economic and regulatory drivers behind each.

Connecting to Precision Agriculture Principles

What is Precision Agriculture?

In our previous lectures on AI in Modern Agriculture, we defined defined Precision Ag as:

- **Right Input** · Applying water, fertilizers, and pesticides precisely.
- **Right Place** · Matching inputs to micro-variations in the soil and crop.
- **Right Time** · Acting dynamically based on real-time data instead of static calendars.

The Automation Transition

Today we move from pure **information processing** (mapping and telemetry) to **physical actuation** (moving parts, automated labor, active intervention):

- **Autonomous Actuation** · How machines physicalize AI decisions in real-time.
- **Scale Adaptation** · How India's smallholders and the US's industrial operations solve completely different physical bottlenecks.

Today's Lecture Structure

01

Core Concepts & Mechanics

The basic physical tools: drones/UAVs, robotic weeders, pickers, and autonomous tractors. tractors.

02

India & US Landscapes

Use-cases, government initiatives initiatives (Kisan Drones, FAA), and and startups in both nations.

03

Direct Comparisons

Contrasting farm scales (USDA vs vs India smallholders), labor bottlenecks, and tech adoption pathways.

04

Class Practice & Synthesis

Interactive 5-minute farm management case scenario, peer peer voting, and academic references.

Agricultural Drones: Sensors and Actuation

Primary Functionalities

1. Aerial Imaging & Surveying · Collecting high-resolution multispectral data to assess crop health, chlorophyll indices, and weed density mapping. (FAO)

2. Targeted Precision Spraying · Executing liquid dispensing (pesticides, nutrients) autonomously over designated micro-zones to reduce chemical waste. (FAO)

3. Variable-Rate Application · Using UAV mapping files to dynamically adjust spray volumes depending on spatial crop needs.

Active UAV Operation: Automated spraying via multispectral-guided variable-rate flight rate flight profiles, executing localized crop protections dynamically (FAO).

Robotic Weeding: Chemical-Free Weed Eradication

The Technology & Mechanics

Robotic weed control combines high-speed computer vision with active thermal or mechanical destruction tools:

- **Real-Time Edge Computing** · Onboard deep learning models identify and differentiate crops from weeds down to sub-millimeter scales under varying field lighting conditions.

- **CO2 Laser Targeting** · Laser-based systems (e.g., Carbon Robotics LaserWeeder) can target weeds for thermal destruction without synthetic chemical herbicides. (Carbon Robotics)

- **Organic Optimization** · Eliminates mechanical soil disturbance, which prevents weed seeds from being brought up to germinate.

LaserWeeder™ in Action: High-throughput thermal weeding zaps 200,000+ 200,000+ weeds/hr with millisecond precision without chemical applications applications (Carbon Robotics).

Robotic Harvesting: Vision, Decisive Gripping & Picking

The Harvesting Bottleneck & Solutions

Harvesting is historically the most labor-intensive farm task. Automation targets seasonal labor gaps:

- **Flying Autonomous Robots** · Drone-based pickers (e.g., Tevel Tech) use artificial intelligence and vision algorithms to fly next to trees, identify fruits, assess ripeness, and gently twist them off. (Tevel)

- **Ground-Based Robotic Arms** · Mobile land-based robots (e.g., Ripe Robotics) use mechanical end-effectors to pick soft stone fruit, protecting delicate crops from bruise damage. (Ripe Robotics)

Flying Fruit Pickers: Intelligent fruit picking drones analyze ripeness, color, and size color, and size before initiating gentle tactile harvest grips (Tevel).

Autonomous Tractors & Broadacre Automation

The Autonomy Architecture

Autonomous tractors allow hands-free tillage, planting, and harvesting across major fields:

• **Geofencing & Mission Planning** · Operators define operational parameters and boundaries. The machine plans and executes pathways dynamically. (John Deere)

• **Obstacle Detection** · Combining LiDAR, radar, and stereoscopic camera systems to scan 360-degrees for animals, humans, debris, or anomalies, auto-halting in milliseconds.

• **Remote Supervision** · Farm managers monitor operation diagnostics, live camera feeds, and health statuses via smartphone or office dashboards.

Broadacre Autonomy: Fully driverless tractor system executing heavy tillage tillage operations across vast crop fields under remote geofenced supervision (John supervision (John Deere).

India: "Kisan Drones" & Smallholder Adoptions

The "Kisan Drone" Model

In India, agricultural drone deployment focuses heavily on targeted aerial applications:

- **Custom Chemical/Nutrient Spraying** · Drones execute automated pesticide spraying across dense, tall, or inaccessible crops (like sugarcane or paddy fields). (Fortune India)

- **Land Mapping & Surveying** · Drones support property identification under initiatives like the SVAMITVA scheme, resolving land boundary disputes.

- **Drone-As-A-Service (DaaS)** · Farmers do not purchase drones. Instead, service startups execute spraying on a rental basis, making it accessible to small-scale holdings.

Drone-as-a-Service (DaaS): Indian cooperatives deploy centralized drone systems drone systems to execute shared spraying on smallholder plots (Fortune India). India).

Regulatory Ecosystem: India's Policy Drivers

Government Push & Rules

The Government of India actively promotes agricultural drone adoption through combined regulation and subsidy:

- **Liberalized Drone Rules** · DGCA established simplified rules for drone operations, removing complex pilot licensing and replacing them with Type Certificates and Remote Pilot Certificates. (DGCA)

- **SMAM Subsidies** · Subsidies up to 100% (for agricultural institutes) or 40-50% (for custom hiring centers and individual farmers) under the Sub-Mission on Agricultural Mechanization.

- **Kisan Drone Scheme** · Financial grants to promote drone purchases for localized farming cooperatives. (Fortune India)

Operational & Scaling Bottlenecks

Despite policy pushes, smallholders face practical constraints:

- **Technical Verification** · Every agricultural drone model must hold DGCA-approved Type Certification to access government subsidies.

- **Input Standardizations** · Safe crop spraying requires standardized liquid compositions to avoid nozzle clogging and optimize droplet sizes.

- **Local Infrastructure** · Custom hiring centers need robust batteries, charging stations, and localized remote pilots to deliver reliable, on-demand spray-as-a-service models. (Fortune India)

Pioneers of Agricultural Drone Tech in India

IoTechWorld

The Agribot Specialist (IoTechWorld)

IoTechWorld is one of India's earliest drone manufacturers to receive DGCA type certification. certification.

- **Agribot** · Specifically optimized for custom drone-spraying programs, handling diverse pesticide and crop nutrition configurations.

Thanos Technologies

Custom Automated Sprayers (Thanos)

Thanos specializes in building advanced drone drone sprayers and software platforms.

- **IFFCO Partnership** · Cooperated with IFFCO to automate liquid nano-urea spray across hundreds of thousands of Indian smallholdings. (DroneLife)

Aereo (AUS)

Broad-scale Land Mapping (Aereo)

Formerly Aarav Unmanned Systems, Aereo specializes in drone-based enterprise mapping mapping solutions.

- **Land Records** · Main driver behind SVAMITVA, generating high-accuracy land maps for Indian villages to support digital title deeds. (PR Newswire)

United States: Autonomous Tractors & Broadacre Autonomy

Broadacre & Specialty Autonomy

U.S. agriculture is characterized by high farm acreage and capital density, directing automation to broadacre vehicles and laser weeding:

- **Autonomous Tillage & Planting** · John Deere's autonomous tractors tillage systems automate heavy land preparation, freeing labor for operational management. (John Deere)

- **Intelligent Herbicide Target** · "See & Spray" technologies use machine learning to differentiate weeds from crops in milliseconds, applying inputs selectively. (Global AgTech Initiative)

- **Laser-Weeding** · Massive active weed destruction with high-intensity laser systems. (Carbon Robotics)

Broadacre Fleet Autonomy: Multi-row autonomous tractor tillage systems systems optimized for large consolidated agricultural operations in the US (John US (John Deere).

Regulatory Ecosystem: US Drone & Tractor Rules

FAA Part 107 Commercial Framework

Commercial unmanned operations in the US operate within strict Federal Aviation Administration rules:

- **Remote Pilot in Command** · Pilots must pass formal aeronautical tests to operate commercial UAVs (under Part 107 guidelines). (eCFR Part 107)
- **Operational Restrictions** · Line-of-sight visual flying (VLOS), height ceilings, and weight limitations (under 55 pounds) restrict large-scale broadacre chemical application.
- **Part 107 Waivers** · Operators must apply for explicit waivers to fly beyond visual line-of-sight (BVLOS), multi-vehicle swarms, or heavy spraying. (FAA)

Autonomous Land Vehicles

Land-based robotics operate inside a different regulatory framework than framework than airspace:

- **High Safety Safeguards** · Automated tillage/planting systems require robust safety sensor suites (LiDAR, thermal) to stop automatically in milliseconds when anomalies are detected.
- **Liability Standards** · Shifting operations liability toward manufacturers and software developers, establishing strict operational validation.
- **Standardization** · USDA and industry groups work toward unifying ISO communication standards (e.g., ISOBUS) to integrate diverse automated implements.

Pioneers of Agricultural Robotics in the US

Carbon Robotics

Laser Weeding (Carbon Robotics)

Carbon Robotics builds massive field-weeding weeding systems designed to reduce farm chemical reliance.

• **LaserWeeder** · Uses high-speed cameras, AI, and CO2 lasers to eliminate over 200,000 weeds per hour without disturbing the topsoil.

Tevel Tech

Flying Fruit Pickers (Tevel)

Tevel designs flying autonomous harvest systems systems deployed across US and European orchards.

• **Fruit Identification** · Small, tethered octocopter drones fly adjacent to orchard trellises, selecting ripe stone fruit and picking them delicately.

Fieldwork & Ripe

Tactile Ground Harvesters (Ripe)

Ecosystem of land-based platforms picking berry berry crops and apples. (Fieldwork Robotics) Robotics)

• **Soft-Tissue Arms** · Advanced soft-robotic fingers duplicate picking pressure, handling highly perishable fruits safely.

India vs US: Structural Farm Scale Divergence

United States: Consolidation

The United States agricultural system is built on immense, consolidated land tracts:

- **Average Farm Size** · Approximately **444 acres** per farm, according to the USDA Census of Agriculture. (USDA NASS)
- **Topography & Layout** · Flat, contiguous fields with rectangular boundaries and robust, heavy infrastructure.
- **Mechanization Target** · Massive multi-row autonomous tractors, laser weeders, and broadacre aerial spraying waivers.

India: Smallholder Fragmentations

The Indian agricultural system is dominantly comprised of small, small, fragmented family plots:

- **Average Farm Size** · Under **1.08 hectares** (~2.6 acres) per operating holder.
- **Topography & Layout** · Interlocking, irregular fields separated by physical bunds (mud levees) with dense obstacle margins (trees, powerlines).
- **Mechanization Target** · Agile, lightweight vertical-takeoff spraying drones (Kisan Drones) that require zero runway or ground space. (Fortune India)

India vs US: Labor Scarcity & Dynamics

United States: Labor Deficits

The primary driver behind automated agricultural technology in the US is acute labor scarcity:

• **Demographic Shortages** · High reliance on seasonal or migrant labor cohorts. Extreme field labor deficits during harvest windows. (FAO)

• **Operational Costs** · High federal minimum wages and complex regulatory compliance burdens drive farms toward permanent capital-intensive robotics. (Cornell)

• **Solved Bottlenecks** · Harvesting and weeding tasks are fully automated first.

India: Demographic Shifts

India's agricultural workforce has high density, but faces distinct distinct localized bottlenecks:

• **Urban Migration** · Younger generations are moving away from manual farm labor, creating sharp, temporary labor spikes during planting and spraying seasons.

• **Occupational Health** · Manual chemical spraying causes chemical inhalation risks. Autonomy targets worker health improvements. (Fortune India)

• **Spray Efficiency** · Spraying crops manually is slow and uneven. Ag-drones solve localized operational bottlenecks rather than replacing the overall farming workforce.

India vs US: CapEx Ownership vs OpEx Services

United States: Heavy CapEx Model

U.S. growers utilize a high-capital, heavy asset ownership model:

• **Heavy Machinery Purchase** · High-scale operations acquire autonomous vehicle platforms directly, treating them as long-term farm assets (Capital Expenditure).

• **Enterprise Integration** · Custom API ecosystems connect John Deere telemetry databases with office accounting systems.

• **Advanced In-House Training** · Dedicated fleet managers monitor and operate robotic systems internally, optimizing regional broadacre logistics.

India: Shared OpEx Service Model

India's small farm scales favor a flexible, low-asset renting layout: layout:

• **Spray-as-a-Service** · Startups and local cooperatives manage ag-drone operations. Farmers rent drone spraying by the acre (Operational Expenditure). (Fortune India)

• **Custom Hiring Centers (CHCs)** · Village-level hiring centers store drones, chargers, and inputs, deploying flight services dynamically.

• **Local Licensed Pilots** · Startups train localized operators to handle compliance, reducing administrative burdens on individual farmers.

Comparative Matrix: Agricultural Automation Models

Metric / Attribute	India Adoption Model	United States Adoption Model
Average Land Scale	**< 1.08 hectares** (~2.6 acres) per smallholding.	**~444 acres** per commercial family farm. [USDA]
Dominant Technology	Lightweight aerial drones (Kisan Drones) for pesticide & nutrient spraying.	Autonomous high-horsepower tractors, laser weeding machines, and automated fruit pickers.
Acquisition Economics	**OpEx (Services)** · Drone-as-a-Service (DaaS) renting by the acre. the acre.	**CapEx (Ownership)** · Direct purchasing, heavy capital asset integration.
Airspace Regulations	Simplified DGCA Type certification, smam-supported drone purchase grants.	FAA Part 107 Commercial Remote Pilot licenses; strict waivers required for BVLOS & swarm spraying.
Primary Bottleneck Solved	Chemical inhalation hazards, field obstacles, and localized labor spikes.	Permanent farm worker shortages, high seasonal labor wages, and night operations.

Class Activity: The Specialty Farm Bottleneck

The Scenario: You are the general manager of a 200-acre specialty organic fruit and vegetable farm. You face dual challenges: intensive weed propagation and weed propagation and acute labor shortages during the harvesting window. You have the investment budget to implement ONE major automated system this automated system this fiscal quarter.

[A] Laser Weeding

Deploy an autonomous laser-weeding robot.

• **Rationale** · Targets weed pressure chemically-free, keeping organic certification.

• **Risk** · High initial machine capital expense (CapEx). (Carbon Robotics)

[B] Drone Spraying

Contract a drone-scouting and spray program. program.

• **Rationale** · Rapid mapping and variable targeted micro-spraying. Low OpEx cost.

• **Risk** · Chemical spraying limitations under organic regulations. (FAO)

[C] Drone Harvesting

Integrate flying autonomous harvesters.

• **Rationale** · Directly mitigates seasonal labor deficit spikes.

• **Risk** · Complex orchard restructuring required for drone flights. (Tevel)

Academic References & Sourcing

Primary Source Documents

- **FAO (2022)** · Food and Agriculture Organization: The State of Food and Agriculture 2022 - Leveraging automation in agriculture for transforming agrifood systems. Link: fao.org/3/cb9479en/online/sofa-2022

- **FAO Drone Guidelines** · E-agriculture in action: Drones for agriculture. Link: fao.org/3/i9085e/i9085e.pdf

- **Cornell Ag Workforce Research (2025)** · Automation will not replace farm labor anytime soon. Link: agworkforce.cals.cornell.edu/2025/07/14/automation-wont-replace-farm-labor-anytime-soon/

- **USDA NASS (2022)** · Census of Agriculture highlights: Farms and Farmland. Link: nass.usda.gov/Publications/Highlights/2024/Census22_HL_FarmsFarmland.pdf

Technology & Policy Materials

- **Carbon Robotics LaserWeeder** · Carbon Robotics Technology Documentation. Documentation. Link: carbonrobotics.com/laserweeder

- **John Deere Autonomous Tractors** · John Deere Autonomous Systems Overview. Link: deere.com/en-us/products-solutions/tractors/autonomous-tractor

- **Federal Aviation Administration (FAA)** · eCFR 14 CFR Part 107 Commercial Small UAS Guidelines and Waiver Programs. Link: ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

- **Fortune India** · Kisan drone business models and startup deployment metrics. Link: fortuneindia.com/enterprise/kisan-drone-makers-have-a-business-model/107619

Week 3 Synthesis & Forward Look

Week 3 Key Takeaways

Today we explored how physical automation matches distinct regional structures:

• **Tech Fit** · Drones suit the irregular smallholder topography of India, while heavy vehicle autonomy and laser weeders suit broadacre US operations.

• **Business Models** · India relies on the decentralized OpEx "Drone-as-a-Service" model, while the US operates primarily on localized capital-heavy fleet ownership (CapEx).

• **Regulations** · FAA Part 107 and DGCA guidelines dictate the pace and boundaries of physical farm execution.

Next Week: Previewing Week 4

Next week, we progress from single-agent vehicles to collective swarm collective swarm networks and system integrations:

• **Drone Swarms** · Deploying and coordinating multiple synchronized UAVs simultaneously over single crop fields.

• **Greenhouse Automation** · IoT sensor grids, automated hydroponic nutrient lines, and vertical farm robotics.

• **Reading Assignment** · Prepare the SMAM Drone Operational Guidelines and FAA Part 107 Multi-Vehicle Waivers documentation.