11.1: AI-Based Spraying Systems

AI-based spraying systems use artificial intelligence — particularly machine learning and computer vision (image recognition) — to identify specific targets (individual weeds, pest-infested plants, or disease symptoms) in real time and apply pesticide/herbicide only where needed, instead of spraying the entire field uniformly. This is a key technology of precision plant protection, often referred to as "see-and-spray" or "spot-spray" technology.

11.2 Concept: From Blanket Spraying to Targeted Spraying

- Conventional sprayers apply pesticide/herbicide uniformly across the entire field, regardless of whether pests/weeds/disease are present at every point.

- AI-based spraying systems use cameras and AI models to detect the actual presence and location of the target (weed, pest, or diseased plant tissue) as the sprayer moves through the field, and trigger individual nozzles to spray only at those specific points.

- This significantly reduces the total volume of pesticide/herbicide used, since healthy or weed-free areas receive no chemical application.

11.3 Main Components of an AI-Based Spraying System

1. Cameras/image sensors – Mounted on the sprayer boom (ground-based) or drone; continuously capture images of the crop/soil surface as the machine moves.

2. AI/machine learning processing unit (onboard computer) – Runs trained computer vision models (often deep learning-based) that analyze the captured images in real time to distinguish crop plants from weeds, or to detect pest damage/disease symptoms on crop foliage.

3. Individually controlled nozzles – Unlike a conventional boom sprayer where all nozzles spray continuously, AI-based systems have nozzles that can be switched on/off individually and very rapidly, based on commands from the AI processing unit, so that only the specific target location receives a spray burst.

4. GPS/GNSS module – Provides location referencing, useful for logging where treatments were applied and for integration with farm mapping systems.

5. High-speed actuators/solenoid valves – Physically open/close individual nozzle flow almost instantaneously, in response to the AI system's detection and targeting commands, even as the sprayer moves at normal field speed.

11.4 Working Principle

- As the sprayer (ground rig or drone) moves through the field, cameras continuously capture images of the crop/soil ahead of or at the nozzle positions.

- The onboard AI model processes these images in real time, identifying the presence and precise location of the target (weed, pest-affected leaf, disease lesion).

- Based on this detection, the system sends a signal to the specific nozzle(s) aligned with the target location.

- The high-speed solenoid valve opens briefly to spray only that specific spot, then closes, while other nozzles (over weed-free/healthy crop areas) remain off.

- This process repeats continuously as the machine travels across the field.

11.5 Advantages of AI-Based Spraying Systems

1. Drastically reduces total pesticide/herbicide usage (often reported as 70–90% reduction in some herbicide spot-spraying applications), lowering input cost.

2. Reduces environmental impact through minimized chemical use and runoff.

3. Reduces the development of pesticide/herbicide resistance in target pest/weed populations, since exposure is more targeted.

4. Improves worker and consumer safety through reduced overall chemical handling and residue.

5. Generates valuable field data (weed/pest maps) useful for future management planning.

11.6 Limitations

- High initial investment in cameras, AI processing hardware, and precision nozzle control systems.

- AI model accuracy depends on the quality and diversity of training data; may struggle with new/unfamiliar weed or pest species not well represented in training data.

- Requires adequate computing power onboard for real-time image processing at normal field operating speeds.

- Regular software updates and technical support needed to maintain detection accuracy.

- Currently more established for certain applications (e.g., weed spot-spraying) than for all pest/disease detection scenarios.

12.1: Autonomous Weeding Robots

Autonomous weeding robots are self-guided, unmanned ground vehicles equipped with sensors, computer vision, and mechanical or other weed-removal tools, capable of navigating through crop fields and removing weeds without continuous human control. They represent an advanced integration of robotics, AI, and precision agriculture for weed management.

12.2 Main Components of an Autonomous Weeding Robot

1. Robot chassis/platform – The mobile base of the robot, typically wheeled or tracked, designed to navigate between crop rows without damaging plants.

2. Navigation system – Combines GPS/GNSS (often RTK-level for high accuracy row-following), along with additional sensors such as LiDAR, ultrasonic sensors, and cameras, to guide the robot along crop rows and avoid obstacles.

3. Vision/AI system (crop-weed detection) – Cameras and machine learning models that distinguish crop plants from weeds in real time, identifying the exact location of each weed for targeted removal.

4. Weed removal mechanism – The actual weed-elimination tool, which may include:

- Mechanical tools – small robotic arms/hoes, rotating blades, or tines that physically uproot or cut weeds at the identified location.

- Precision spot-spraying – a targeted micro-dose of herbicide applied directly to the detected weed (similar concept to AI-based spot-spraying, but weed-specific and often at plant-level precision).

- Laser or electrical weeding tools – emerging technologies that use a focused laser beam or electric discharge to destroy weed tissue without physical contact or chemical use.

5. Power source – Battery (electric) or, in some larger designs, a small engine; electric power is common in smaller autonomous robots due to lower noise, no emissions, and simpler control integration.

6. Onboard computer/control unit – Coordinates navigation, vision processing, and actuation of the weed removal mechanism, often with wireless connectivity for remote monitoring and software updates.

12.3 Working Principle

- The robot is deployed into the field (autonomously navigating pre-mapped rows or guided initially by an operator/GPS boundary).

- As it moves along the crop row, the vision/AI system continuously scans the ground, distinguishing crop seedlings from weeds based on trained image-recognition models.

- Upon detecting a weed, the robot's control system directs the weed-removal mechanism (mechanical tool, spot-sprayer, or laser) to precisely target and eliminate that specific weed.

- The robot continues this process autonomously across the field, often able to operate continuously (including at night, in some designs) without an operator physically present.

- Data on weed occurrence/location may also be logged for future field mapping and management planning.

12.4 Advantages of Autonomous Weeding Robots

1. Drastically reduces manual weeding labour requirement, addressing chronic labour shortage during peak weeding periods.

2. Enables precise, plant-level weed removal — including intra-row weeds close to crop plants, which conventional mechanical/power weeders struggle to address.

3. Can operate continuously (day/night, in suitable designs) without operator fatigue.

4. Reduces or eliminates herbicide use (for mechanical/laser types), supporting organic and sustainable farming practices.

5. Generates valuable field weed-occurrence data for long-term weed management planning.

12.5 Limitations

- Very high initial investment cost, currently limiting adoption mainly to well-resourced or large commercial farms and research institutions.

- Requires reliable navigation infrastructure (GPS/RTK signal, or pre-mapped field boundaries) for accurate row-following.

- AI detection accuracy depends on training data quality; may struggle to distinguish crop and weed species not well represented in the model's training set, or when weeds closely resemble the crop at early growth stages.

- Limited field capacity (area covered per hour) compared to larger conventional power weeders, though this is improving with newer designs.

- Requires technical expertise for setup, maintenance, and troubleshooting.

- Performance can be affected by challenging field conditions (uneven terrain, waterlogging, dense residue).

13.1: Sensor-Controlled Pesticide Application

Sensor-controlled pesticide application refers to spraying systems that use real-time sensor feedback — such as canopy density/height sensors, crop presence sensors, or ground speed sensors — to automatically adjust spray output (rate, timing, or on/off status of individual nozzles), ensuring pesticide is applied efficiently and only where and when needed, without necessarily relying on full AI-based image recognition.

13.2 Difference from AI-Based (See-and-Spray) Systems

- AI-based systems (Chapter 11) primarily use image recognition/computer vision to identify specific targets (individual weeds, pests, disease symptoms) and are more focused on "what" to spray.

- Sensor-controlled systems more broadly include simpler, well-established sensor types (ultrasonic, infrared, ground speed) that adjust "how much and when" to spray based on physical presence/absence of canopy, canopy size, or travel speed, and can be used independently of or alongside AI-based target recognition.

13.3 Types of Sensors Used

1. Canopy/foliage sensors (ultrasonic or infrared/optical) – Detect the presence, height, or density of crop canopy as the sprayer passes; used to switch nozzles on only where canopy/plants are present (e.g., in orchards with gaps between trees, or intermittent row crops), avoiding wastage of spray on bare ground/gaps.

2. Ground speed sensors – Measure the actual forward speed of the sprayer (via radar, wheel-mounted, or GPS-based sensors) and automatically adjust the pump/nozzle flow rate to maintain a constant application rate (litres/hectare) even as travel speed varies (e.g., when slowing down at turns or on uneven ground).

3. Boom height sensors – Maintain a constant boom height above the crop canopy (important for uniform spray coverage and reducing drift), automatically raising/lowering the boom using sensor feedback as field/canopy height varies.

4. Wind speed/direction sensors – Some advanced systems include wind sensors that can pause or adjust spraying if wind conditions exceed safe thresholds, reducing drift risk.

5. Pressure/flow sensors at individual nozzles – Monitor actual output at each nozzle, detecting blockages or malfunctions in real time and alerting the operator.

13.4 Working Concept

- Sensors continuously monitor relevant parameters (canopy presence/height, ground speed, boom height, wind conditions, nozzle flow) as the sprayer operates.

- A control unit processes this sensor data in real time and sends commands to actuators (nozzle solenoid valves, boom height hydraulics, pump speed controller) to adjust the spray operation accordingly.

- For example: as ground speed decreases at a turn, the flow-rate controller reduces pump output/nozzle flow proportionally, keeping the per-hectare application rate constant; where canopy sensors detect a gap (no plant present), the corresponding nozzle is automatically switched off.

13.5 Advantages

1. Maintains consistent application rate (litres/hectare) regardless of variation in travel speed, improving accuracy and reducing over/under-dosing.

2. Reduces pesticide wastage by avoiding spraying gaps/bare ground where no crop/canopy is present.

3. Improves spray deposition uniformity through automatic boom height control.

4. Reduces drift risk through wind-responsive spray control.

5. Provides real-time fault detection (nozzle blockage/malfunction alerts), reducing missed-spray areas.

13.6 Limitations

- Additional sensors and control electronics increase equipment cost compared to basic sprayers.

- Requires regular sensor calibration and maintenance (e.g., cleaning of ultrasonic/optical sensors) for continued accuracy.

- System complexity may require trained technicians for troubleshooting.

- Sensor performance (e.g., ultrasonic canopy sensors) can be affected by dust, extreme weather, or unusual canopy shapes.