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SUSTAINABLE AGRICULTURE TECHNOLOGIES II

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EDITOR

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Preface

Even while global agricultural production is always rising, it cannot keep up with demand. The population growth indicates that the demand increase will last into the future. On the other hand, the issue becomes even more crucial as arable land becomes scarcer in nations that can already supply the demand for agricultural products and as opportunities to boost agricultural production become less likely. The application of technology in agriculture directly correlates with an increase in production. Food demand would increase 70% by 2050 in pace with the increasing population rise. According to a UN report, 9.9% of the world's population still experiences hunger, making the idea of providing food for roughly 10 billion people a difficult task. Since environmental changes are difficult to predict, farm technology innovation is necessary.

The most significant technological advancements in agriculture have been in fields like indoor vertical farming, automation and robotics, livestock technology, contemporary greenhouse techniques, precision agriculture and artificial intelligence, block chain, energy efficiency and animal technology. Technology that increases farm efficiency and automates the crop or livestock production cycle is known as farm automation and is frequently coupled with smart farming. A growing number of businesses are focusing on robotics innovation to create robots that can automatically water plants, sow seeds, and operate tractors and harvesters.

Companies engaged in precision and digital agriculture are creating technologies that will enable growers to maximize crop yields by managing every aspect of crop production, including moisture content, pest stress, soil quality, and microclimates. Precision agriculture helps farmers enhance productivity and control expenses by offering more precise methods for planting and producing crops.

It is extremely important to use precision agriculture technologies for sustainable agriculture in meeting the food needs of the increasing world population. Especially for sustainability and food safety. The development of sustainable agricultural technologies is extremely important, especially for the processes from input production to the use of inputs in agricultural production. It is essential to apply pesticides with the right technologies, conserve energy when manufacturing inputs, boost crop yields through artificial pollination, and shield crops from hail damage. Achieving long-term food security and raising productivity in agriculture require innovation. Smart farming Technologies (digital farming) for sustainable agricultural development are already a key driver in innovation and tech in agriculture.

In this book, modern and smart agricultural technologies that reduce the environmental risks, consumption and energy requirement in manufacturing process of inputs in agricultural production, protect the product, improve the yield, and help farmers in their decision-making processes are discussed.

Prof. Dr. Ali Bayat

Editor

CHAPTER I

AGRONETS AND A CASE STUDY: ANTI-HAIL NETS

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INTRODUCTION

Agricultural nets can truly be considered plant protection products, despite the fact that when the term "Plant Protection Products" is used, agricultural pesticides typically come to mind (İtmeç et al., 2022). This is because these products' primary function is to protect the plant. The main agricultural applications for AgroNets include: soil cloth, harvesting, packaging, post-harvest processes, protection against meteorological dangers, insects, and small animals, and reduction of sun radiation. While various insect net kinds' air flow resistance has been extensively studied, little is known about the radiometric characteristics of different net types. The radiometric characteristics of agricultural nets, such as their transmissivity, reflectivity, shading factor, and ability to alter the quality of radiation passing through the net, affect both the aesthetics of the netting system and the quality of the agricultural production (Figure 1).

Different structural characteristics of nets, such as the shape and dimensions of the fibers and their meshing, shape and form of the threads, fabrics, and shading factor, affect the physical characteristics of nets, including their weight, shading factor, radiometric properties, porosity, air permeability, mechanical properties, and durability. Knowing how structural aspects affect the net's physical characteristics, starting with the performance requirements, enables proper membrane design (Castellano et al, 2016).

High density polyethylene (HDPE) is the basic material that is most frequently used to make agricultural nets. Additionally, polypropylene (PP) is utilized as a primary raw material for the creation of nets, primarily non-woven layers. Because there are no data from European agricultural and manufacturing groups, it is impossible to estimate the usage of agricultural nets in Europe. Additionally, because a portion of their production is actually sold for non-agricultural uses, such as the construction of temporary fences, anti-insect nets for windows, and fishing nets, the net producers are unable to define the consumption of agricultural nets (Scarascia et al., 2005). Polyethylene materials provide the following advantages:

- It has the longest lifespan of any of the netting materials.
- It won't decay.
- Very little shrinkage, no expansion, and little humidity effect.

- It is much lighter than nylon or polyester.
- It floats on water.
- UV protection is chemically linked and injected prior to filament extrusion in polyethylene.

In comparison, after manufacture, nylon or polyester is UV coated, and this is the first item to wear off, exposing the netting to UV radiation. Nylon degrades quickly and expands and contracts with variations in humidity.

The key element influencing AgriNet demand is the use of agricultural nets in horticulture. Vertical or horizontal netting is used depending on the type of crop. These nets are used to support plant and vegetable trellis, but they are environmentally friendly and composed of non-toxic materials, which promotes the growth of agriculture nets markets (Figure 1).

Figure 1. Agronet applications that used for plant protection commonly used types

Characteristics of the AgroNets

The ideal qualities of the materials used to create agricultural nets largely rely on the application in issue. However, there are a few crucial qualities that these nets, and particularly those employed for exclusion, should possess.

Durability

UV light is a significant factor affecting the mechanical characteristics of the nets. Any net used for farming will be exposed to a variety of circumstances that may affect its lifetime and durability. According to Castellano et al. (2008a), the majority of commercial nets have a solar radiation resistance of roughly 17–33 GJm^{-2}, or 5–6 years of solar irradiance in mild climes like the Mediterranean region or 3–4 years in tropical locations. The net lifetime is also influenced by other elements, including the polymer chain length, sheet thickness, additives utilized, weather conditions (such as wind and hail storms), exposure to agrochemicals, contact with corrosive compounds, etc. (Scarascia-Mugnozza et al., 2012).

Shading Factor

A high shading factor can be considered to be a positive feature when one desired result of applying the net is reducing the incoming solar irradiation that can cause plant surface temperature to rise above damaging levels. When one of the objective outcomes of using the net is to reduce the incoming sun irradiation, which can cause plant surface temperature to rise above dangerous levels, a high shade factor can be regarded a favorable characteristic. A high shade factor may be deleterious, particularly in temperate areas, because shading can have a significant impact on photosynthetic rates, crop yields, and fruit ripening (Mukherjee et al., 2017). The shading factor can be adjusted by altering the net color, with black, green, red, yellow, blue, white, and grey nets, as well as clear nets, being utilized for various purposes (Castellano et al., 2008b).

Shading nets are designed to minimize solar radiation in order to lower greenhouse air temperatures or to reduce light levels for a variety of shadeloving crops such as some decorative plants. The shading factor of the net determines the efficiency of shading systems.

The material's light transmittance and shading rates are expressed as a percentage. A light transmittance measurement equipment and a lux meter are utilized in measurements for this purpose. The covering materials are carefully fastened to 50×50 mm frames during measurements. Each sample is measured twice: once while empty and once when full. The initial measurement value is determined without stretching the material. Subsequent measurements are taken by tautly attaching the sample material to the measuring equipment frame. The light transmittance of the samples is determined using the following equation as a consequence of the measurements.

$$\tau = \frac{I_d}{I_b} x100$$

τ= Light transmittance of the material (%)

I_d = Amount of light passing through the material (lux)

I_b = In case there is no material in the measuring device, the amount of light (lux)

Beside this, an another factor, the void ratio is determined for knitted cover materials. To determine the void ratio, the material is passed through the scanner and transferred to digital media. By performing operations on the image transferred to the computer, the void ratio is determined with the help of some programs.

Mesh Size

Mesh size is proportional to net porosity, which is defined as the ratio of open to total net surface area (Figure 2). Net porosity is significant since it influences other parameters like as well as the weight, shading factor, and ventilation rate. Reduced mesh size, on the other hand, may be required to keep little insects out. This differences may develop as a result of the varied morphologies of the insects were specifically targeted. Mesh size is proportional to net porosity, which is defined as the ratio of open to total net surface area. Net porosity is significant since it influences other parameters like as well as the weight, shading factor, and ventilation rate. Reduced mesh size, on the other hand, may be required to keep little insects out. This differences may develop as a result of the varied morphologies of the insects were specifically targeted.

(a) **(b)**

Figure 2. Anti-hail nets weft fibres and wrap yarns (a), anti-insect AgroNets (b)

General Properties

Different structural characteristics, such as the type of material, the type and dimensions of the threads, the texture, the size of the mesh, the porosity/solidity, and the weight of the net; radiometric characteristics, such as color, transmissivity/reflectivity/shading factor; physical characteristics, such as air permeability; and a number of mechanical characteristics, including tensile stress, strength, elongation at break, and durability. There aren't many norms that describe the other mechanical characteristics of agricultural nets. The plastic strain and the tensile strength in the warp and weft directions are the two mechanical properties of nets that are most crucial. Some manufacturers express the tensile strength as the ratio of the breaking load to the cross-sectional area of the sample, expressed in N/mm^2.

Prior to the manufacture of the compound, chromatic additives are mixed with HDPE grains to create the color of the net. The most popular net colors are translucent, transparent green, or black. For applications where the shading impact of the net is thought to be a detrimental influence of net performances, transparent nets are used. Black nets are typically utilized for shade installations when it is preferable to reduce incoming solar radiation (Figure 3).

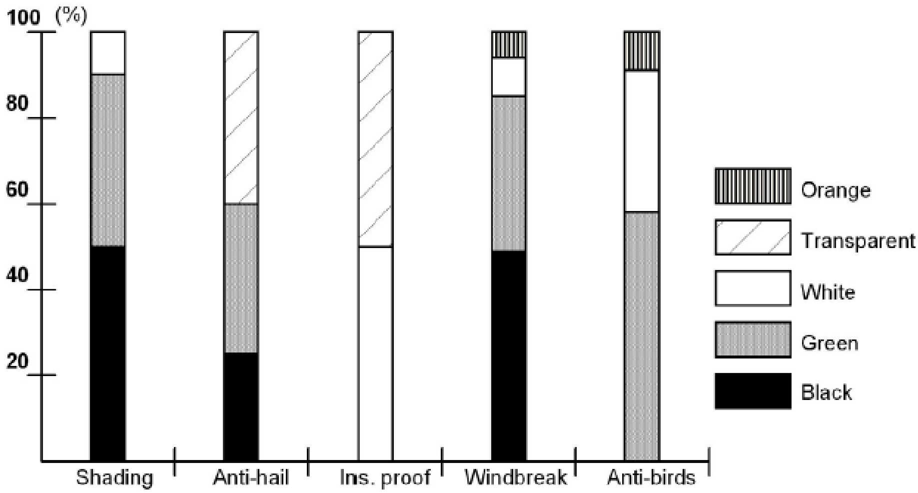


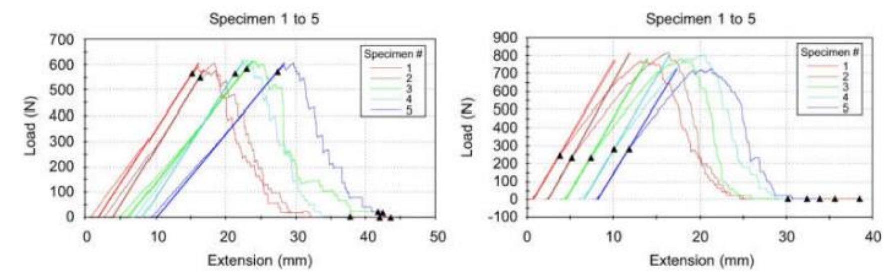
Figure 3. Colors of nets depending on their agricultural application in Italy (Castellano and Russo, 2005)

The Test Procedureces for AgroNets

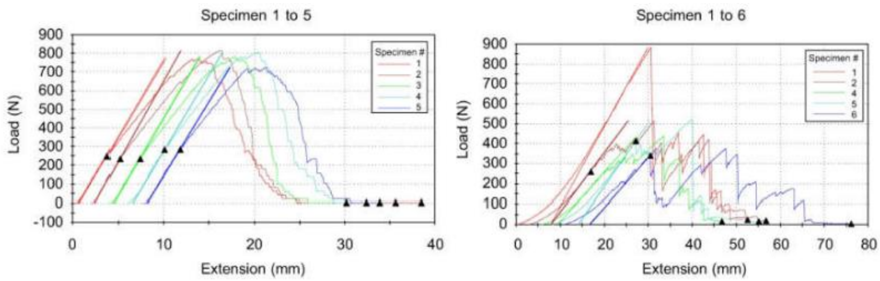
In terms of agricultural nets, there is no normative scenario in Europe. Only a few national guidelines particularly addressing agricultural nets and films exist at the moment. There are a number of Italian Standards for nets that cover a wide variety of agricultural net characteristics. Other national standards, such the French standard NF EN 13206 (NF, 2002) and the Italian standards UNI 9738 (UNI, 1990) and UNI 9298 (UNI, 1988), deal in part with agricultural films (Castellano et al., 2008c).

Tensile testing are essential for determining whether plastics are sustainable. In addition to spectral transmissivity, tensile tests are run to assess the stress-strain characteristics, yield strength, brittleness, and fatigue limit of plastic nets in order to estimate their sustainability. The most popular tensile tests are used to gauge how a material will react to pulling pressure and establish its breaking point. Materials that are prone to necking and plastic deformation are better suited for agricultural applications where severe meteorological threats are frequent (Vega et al., 2009).

Similar to windbreak nets and anti-insect nets, anti-hail nets must exhibit the necessary mechanical characteristics, such as plastic deformation and elongation. However, linear and nonlinear elastic and linear elastic behavior in the weft and warp directions, respectively, must be present in plastic nets for them to endure the impact pressure of hail (Briassoulis et al., 2007a). For nets used in shading applications, plastic nets' optical qualities are a crucial consideration. Significant lateral contraction and brittleness are two traits that are common in curves. As a result, farms at danger of hailstorms should be equipped with nets with higher impact strengths. These nets should be produced specifically for the farm applications and weather patterns (Figure 4).



(a)



(b)

Figure 4. Stress-strain curves for antihail agricultural plastic nets (plastic type: FRU44) (a), Stress-strain curves for agricultural shading nets used in farms (plastic type: OMBR70) (b) (Maraveas, 2020)

In order to characterize agricultural nets with regard to their tensile qualities, impact resistance, and mesh breaking resistance, three basic test techniques were created or modified and proposed. A method based on the ISO 10319:1993 standard test procedure for geotextiles was introduced and assessed for the tensile properties. Using ASTM D 1709-01: Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method—Method

B, it was discovered that impact resistance was adequately evaluated. A method based on the ISO 1806 Standard for fishing nets was modified, assessed, and suggested with regard to mesh breaking resistance.

Case Study: Determination of Anti Hail Strength

Preliminary Control

In the preliminary control of product protective nets and cover materials, manual and visual inspections are applied, taking into account the material, weaving properties and production status. During the preliminary control, it is checked whether there is any deterioration in the smoothness of the stitches of the sample materials, the homogeneity, strength, color of the knitting gaps, etc. properties should be checked.

Application of the Test Procedure

According to standard EN ISO 13934-1:2013 Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method (ISO 13934-1:2013), it is easy to determine maximum force that exerted on the net. Accordingly, the sample taken from the net is attached to the two jaws of the device where the tensile test is performed. The upper jaw of the device is movable and the lower jaw is fixed. On the other hand, if the Force-Expansion graph obtained as a result of the tensile test is converted into a Force-Extension curve, the graph in Figure 5 is obtained.

To measure the breaking strength and elongation of knitted cover materials, five samples are taken in the warp and weft directions. For agricultural net testing, the sample width must be at least 100 mm. The measuring length between the measuring jaws should be 50 mm. The breaking strength test speed should be 100 mm/min. Sample holders must be 120 mm wide and 40 mm long (>25mm, to prevent slippage).

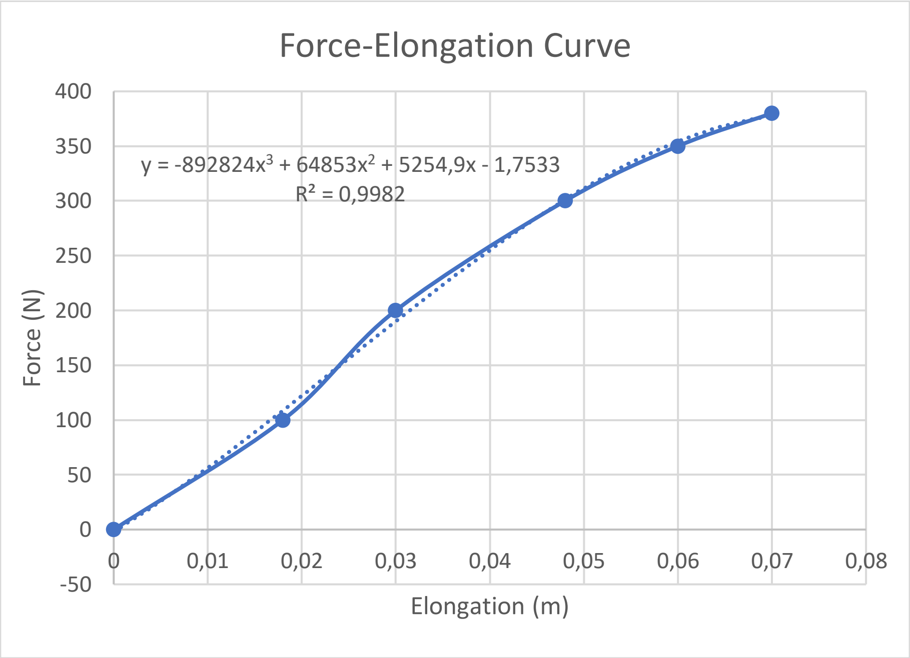


Figure 5. Force-Elongation curve of the net used for agricultural purposes

When this curve converges to a function, it is possible to say that the R^2 value is high and this function describes the curve well. The area under this curve gives the amount of energy required for rupture (Beer et al., 2016).

$$\int_0^{0,07} -892824x^3 + 64853x^2 + 5254{,}9x - 1{,}7533\ dx$$

Then;

E_{net}=14.78 joule was calculated.

This ideal is the energy required to tear a net that has no manufacturing defects.

For example;

The diameter of a hazelnut-sized hailstone is around 1 cm. The weight of a hailstone of this volume is approximately 4.8 g. The maximum terminal speed of a hailstone of this size before hitting the ground is 14 m/s, considering air resistance (Dieling et al., 2020).

Accordingly, the kinetic energy when the hail hits (Briassoulis et al, 2007b);

$$E = \frac{1}{2} m V^2$$

E_{hail}= 0.05 joule was calculated.

In this case, since E_{net}> E_{hail}, there will be no break in the net. Accordingly, any hailstone smaller than 4 cm in diameter and located in the area limited by the black dashed lines in the graph given in Figure 6 cannot damage the net.

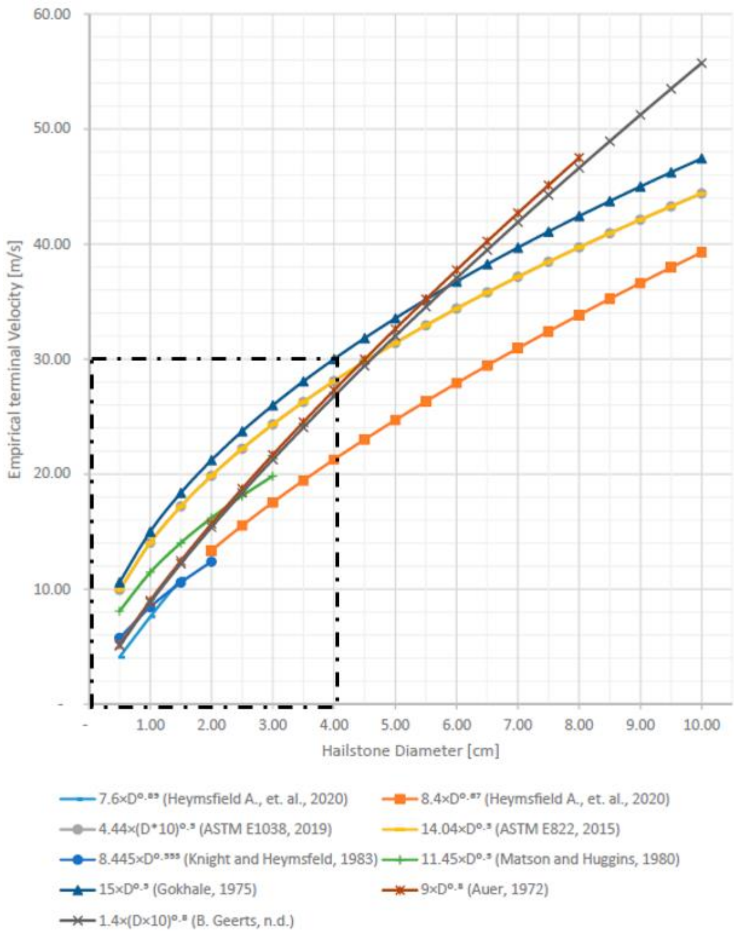


Figure 6. Diameter-Terminal Velocity relationship of hailstone (Dieling et al., 2020)

CONCLUSION

Researchers have presented various anti-hail net experiences. It could be sense to design experiments where a wider range of different anti-hail nets (with different colors and structures) would be combined. More research would need to be done in order to gather reliable data on specific, highly interesting topics (such as the effect of anti-hail nets on the growth and movement of pests, the development of diseases, the quality of fruits, the vegetative reactions of cultivated plants to conditions under anti-hail nets, etc.), as the current research demonstrates that some topics and factors are not sufficiently explored and that knowledge on the effects of anti-hail nets is lacking. Future research on anti-hail nets and their effects should include less studied subjects. More consistent results that are desperately needed in practice would result from more cogent findings and a thorough knowledge of these implications in different researches.

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CHAPTER II

VARIABLE RATE PESTICIDE APPLICATIONS TO ORCHARD TREES WITH REAL-TIME SENSORS

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INTRODUCTION

Chemicals are frequently necessary in agriculture to protect crops. Although improvement studies are carried out in order to reduce pesticide use in agriculture and prevent pesticide drift, transportation of droplets by air flow (Bayat et al., 2011), charging with static electricity (Bayat et al., 1994), using new nozzle technologies (Soysal and Bayat, 2006) and adding various additives into pesticides (İtmeç et al., 2022), problems in pesticide applications continue. Especially applying pesticides to orchard trees creates a more complex situation. On the other hand, the use of pesticide sprays has made it possible to produce a large quantity of high-quality goods for orchards. Nevertheless, in spite of these successes, conventional sprayers are incredibly wasteful because they constantly release the same amounts of chemicals into the field, regardless of the type of plants present, the structure of the canopy, or the density of the leaf foliage. Because canopies vary in space, a single dosage might not be sufficient for the entire orchard.

Variable rate pesticide applications to orchard trees with real-time sensors refer to the use of technology and data to optimize pesticide usage in orchard farming. Real-time sensors, such as weather stations, soil moisture sensors, and pest monitoring systems, are used to collect data about the environmental conditions and pest pressure in the orchard.

This data is then used to determine the appropriate amount and timing of pesticide application to ensure effective pest control while minimizing environmental impact and unnecessary pesticide use. By adjusting the pesticide application rates based on real-time information, farmers can target areas of higher pest activity and reduce pesticide application in areas with lower pest pressure.

The use of variable rate pesticide applications with real-time sensors offers several benefits. Firstly, it allows farmers to make data-driven decisions and optimize pesticide usage, reducing costs and potential negative effects on the environment. Secondly, it improves the accuracy and efficiency of pesticide application, ensuring better pest control without excessive use of chemicals. Finally, it enables farmers to manage pest outbreaks more effectively and respond promptly to changing environmental conditions.

One of the areas of current agricultural spraying application research focus is precision variable rate spraying. Growers can use variable rate canopy spraying to apply plant protection products in an economical and environmentally responsible way, as well as to apply pesticides at a target with a customized volume rate based on canopy size. Because canopies vary widely in space, understanding their structural features is essential to enhancing the effectiveness of the spray application method for tree crops. By increasing the effectiveness of the pesticide treatments, the incorporation of electronic systems in the creation of new equipment contributes to a decrease in operating and environmental expenses. For example, devices that spray exclusively when plants are present, rather than in the spaces between them, have already been created for apple and peach tree cultures (Giles et al.,1987). A primary objective of real-time operating parameter adjustments based on target density for orchard and vineyard spraying systems is to maintain droplets in the canopy, which enhances spray deposition and minimizes spray drift.

Overall, variable rate pesticide applications to orchard trees with real-time sensors help improve the sustainability and effectiveness of pest management practices in orchard farming, ensuring the health of the orchard while minimizing the negative impact on the environment.

The foundations and agricultural applications of the main technologies used for real-time spray target recognition and geometrical characterization of orchard tree plantations are presented in this chapter. The effectiveness of systems based on infrared, ultrasonic, light detection and ranging (LIDAR), and stereo vision sensors in detecting spray targets was examined in turn.

Technology based on infrared sensors for sensing

Everything that has a temperature higher than absolute zero radiates heat energy. An electrical sensor known as an infrared sensor detects infrared light emitted by objects inside its range of vision. The only way this method functions is by detecting infrared light that is reflected or emitted by objects (Figure 1). The automatic target detection system makes use of an infrared detector. Automatic target-detecting orchard sprayers use infrared sensor-detecting techniques to identify targets and automatically regulate the spraying system. Because infrared sensor detectors are so inexpensive, it is easy to market these sprayers. Developed nations including the United States, the European Union, and Russia are creating automated target-detecting sprayers that make use of infrared imaging methods (Moltó et al., 2001). These sprayers are still in the experimental stage due to issues with infrared image processing.

Figure 1. The application of infrared sensors on pesticide application equipment in an orchard setting

Based on automated infrared target detection and electrostatic spraying methods, He et al. (2011), created a precision orchard sprayer (Figure 2). In order to identify various fruit tree shapes and send signals to the control system, the sensors are pointed at the top, middle, and bottom segments of the tree canopy. The new automatic target-detecting orchard sprayer with an infrared sensor can save over 50–75% of pesticides, increase utilization (above 55%), control efficiency, and drastically lower environmental pollution caused by pesticide application, according to experimental results.

Figure 2. An automatic target-detecting air asisted sprayer working in orchard (He et al., 2011)

A red/near-infrared reflectance sensor system was created by Bargen et al. (1993) to identify plants. Spectra-radiometry technology has been used to determine these reflectance characteristics. Based on the unique reflectance properties of plants, soil, and residues, plants can be detected. The red and near-infrared ray photodetectors' spectral bandwidth sensitivities were chosen using optical filters. To give a clearer signal that a live plant is present in the sensor's field of view, the reflectance values were digitalized and added to a normalized difference index.

Large, dense target reflectors in bright light are better suited for the application of infrared detection technology in plant targeting. For plants with high leaf reflectivity, it will yield better detection results and obtain the best detector sensitivity close to the midpoint of the detection distance. The operation of an infrared detecting system for an automatic target orchard sprayer was difficult to operate in a rough environment due to design flaws, such as the short detectable distance, complex circuit, and high cost of the automatic target detector. This was the case, however, when using infrared target detection for plant pesticide spraying. Plants emit infrared radiation, which is detected by infrared (IR) sensors. Temperature and humidity levels have minimal effect on the accuracy of infrared sensing. Nevertheless, the accuracy of these sensors can be impacted by driving speed, plant and leaf appearance, and light intensity. It is known that low light levels, such as those experienced at dawn and dusk when red light is more prevalent, can cause an infrared sensor to malfunction for about half an hour. IR sprayers could be used in standard mode at dawn and dusk by using a spray controller override. Because IR sensors cannot resolve features of plant structure, they are best suited for simpler applications, like turning on and off a plant's sprayer.

In conclusion, infrared sensors for tree canopy sensing in pesticide applications (Figure 2) offer a technologically advanced, efficient, and environmentally friendly approach to managing orchard health. This technology helps in optimizing pesticide usage, improving crop quality, and reducing environmental impact, thus benefiting both farmers and the ecosystem.

Ultrasonic sensor-based technology for detection

Ultrasonic sensor-based detection technology in orchard sprayers represents a significant step forward in precision agriculture. It enhances the efficiency and effectiveness of pesticide application, reduces environmental impact, and provides valuable data for orchard management, all of which contribute to more sustainable agricultural practices.

Three components are necessary for these sensors: an ultrasonic wave emitter, a chronometer, and a wave receiver. Their method of operation involves timing the ultrasonic wave's flight from the point of emission to the point of detection following its reflection off an object. One possible use for an ultrasonic sensor is for quick tree volume quantification in orchard management. The data may be applied to a grove to apply agrochemicals at varying rates. When there was no vegetation in front of the sensors, there was no spraying; when there was some vegetation, there was half-spraying; and when the sensors detected the width of the canopy above a predetermined threshold, there was full spraying. This accomplishment paved the way for a constant fluctuation in flow rate based on canopy variability along rows of citrus groves, vineyards, and fruit orchards (Gil et al., 2007; Escolà et al., 2013)

Various studies have been carried out to measure canopy dimensions in groves automatically. Ultrasonic sensors have been used in agriculture for many years for various applications (Planas et al., 2011). Detection and range is one of these uses to extract structural information from trees. The first developments in this field concerned the use of pesticides and other plant protection agents in various orchards.

A vertical mast or a sprayer mounted with numerous ultrasonic sensors were used in the initial suggested systems to calculate canopy volume (McConnell et al.,1983; Giles et al., 1988). It was not feasible to use this information in real time due to the state-of-the-art application technologies. Only the detection of canopy presence has been documented as a use case for ultrasonic sensors (Brown et al., 2008). Using this method, the sprayer could only be used when the canopy was in front of it. Citrus trees sprayed at a constant distance was another application (Moltó et al., 2000). Based on information gathered from sensors, the nozzles were mounted on a movable arm that follows the tree's edge. 50 and 75 centimeters separated the ultrasonic sensors.

The same authors enhanced a different sprayer that could apply three distinct dosages based on an ultrasonic sensor-based canopy width estimate (Moltó et al., 2001).

Using the action of two electro valves at each boom section, Moltó et al. (2001) created a prototype to turn off the spray in the space between two tree canopies and with the potential to compensate for the variation of canopy volume at the beginning and end of each tree (Figure 3). An electronic control system has been developed to adjust the product's dosage based on the actual amount of leaf mass in an automatic sprayer. This system is based on an inexpensive, 8-bit conventional microcontroller that is programmed to sense the shape of the tree using two ultrasonic sensors. The microcontroller then actuates multiple electro-hydraulic valves that are positioned on a specially made hydraulic circuit. The central section of the tree, which has more vegetation in globular-shaped canopies, is where the system permits spraying larger dosages. The system preserved the treatment's quality while achieving savings of up to 37% of the product in field test experiments. The size, form, and spacing of the trees in any given orchard determine these savings.

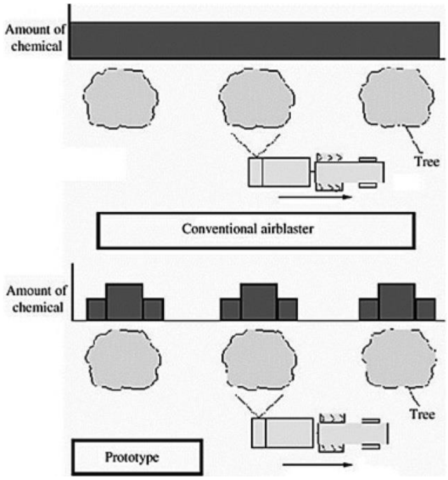
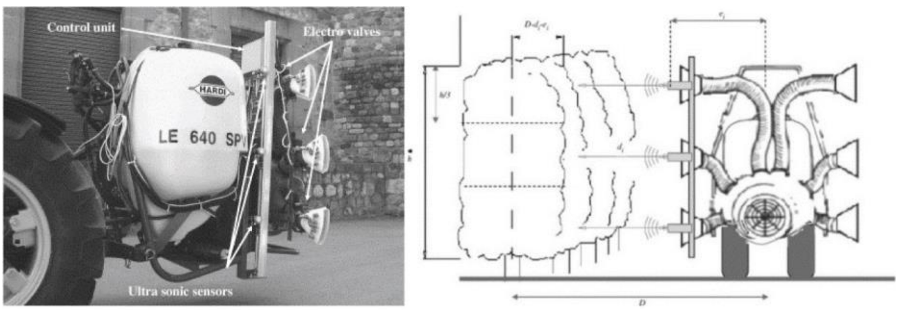


Figure 3. Chemical applied by a conventional airblast sprayer and by the prototype with ultrasonic sensors (Moltó et al., 2001)

According to Gil et al. (2007), target detection using ultrasonic sensors can be utilized to modify the dosage given in accordance with the concepts of variable-rate technology. Three ultrasonic sensors and three electro valves were installed in a multi nozzle air-blast sprayer (Figure 4) to adjust the nozzle flow rate in real time based on crop width variations. At a canopy of 0.095 l/m^3, a variable-rate application based on the tree row volume principle was contrasted with a constant application rate of 300 l/ha. The changes in crop width detected by the ultrasonic sensors were used to adjust the overall flow rate that the nozzles sprayed. In comparison to the constant rate application, 58% less liquid was applied on average, yet the deposition on the leaves was the same for both treatments.



(a) (b)

Figure 4. (a) Prototype sprayer with electro-valves and ultrasonic sensors; **(b)** working principle of the prototype (Gil et al., 2007)

Llorens et al. (2011) used ultrasonic sensors to detect canopy characterizations in tree crops and vineyards. Ultrasonic sensors measure the distance to the external surface of the canopy by counting the lapse time between emission and reception of the emitted signal. The frequency of the pulses from the ultrasonic sensors was 20 Hz and divergence angle was 5°. The sensing range, according to manufacturer, was 400–3,000 mm and the accuracy 1.5%. Calibration curves (xs = 14.215 v + 181.21; R2 = 0.9997) was established for all three sensors, in order to verify the relation between output signal emitted, v (ranged from 0 to 10 V) and distance xs (m) to the external layout of the canopy. This distance was then transformed (Figure 5) into crop width (m) according the equation;

$$C_{WU} = \frac{r}{2} - e - x_s \qquad (1)$$

where CWU: crop width of the semi canopy (m); e distance from the center of the row to the sensor (m); and x_s measured distance from sensor to external layout of the crop (m).

Total and partial canopy surface for every single ultrasonic measurement was calculated according to Equation (2) in which the average canopy width measured for every ultrasonic sensor is assumed constant in all the assigned canopy height:

$$C_{SU} = \sum_{i=1}^{3} (C_{WU})_i \times \frac{1}{3} \times C_{HM} \quad (2)$$

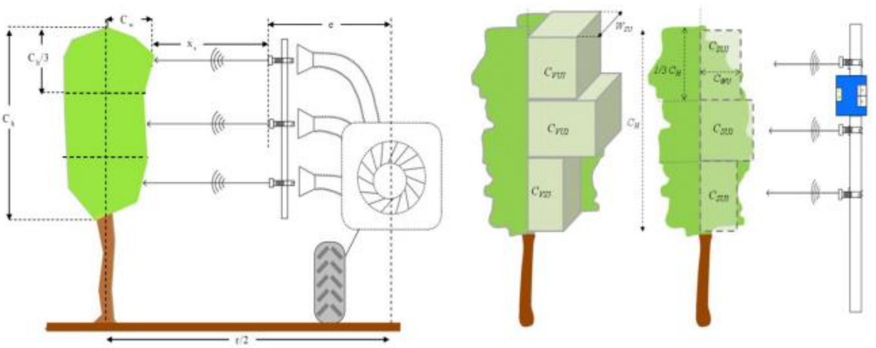


Figure 5. Functioning principle of ultrasonic sensors. Distance to the external layout of the crop (left) can be transformed into crop volume (right)

An electronic control system (Figure 6) for pesticide application proportionate to the canopy width of tree crops was created by Solanelles et al. (2006). Positioned atop an air-assisted sprayer was a prototype electronic control system consisting of ultrasonic sensors and proportional solenoid valves for a proportionate application to the tree crop canopy width. The relationship between the maximum tree width of the orchard and the actual tree width as determined by the ultrasonic sensors was used to adjust the sprayer flow rate. In order to evaluate the system's performance in various crop geometries, the prototype was tested in apple, pear, and olive orchards. In order to measure the spray deposits for every treatment on the same samples and minimize sampling variability, metal tracers were employed. In the case of the olive, pear, and apple orchards, respectively, liquid savings of 70, 28, and 39% relative to a conventional application were noted. This led to reduced spray deposits on the canopy but an increased ratio between the total spray deposit and the liquid sprayer output.

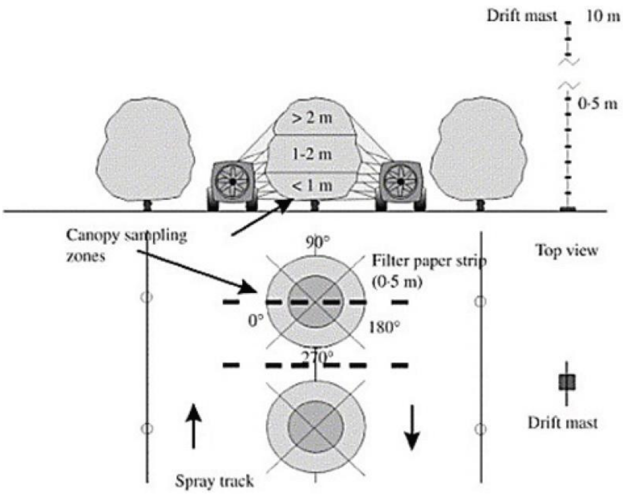
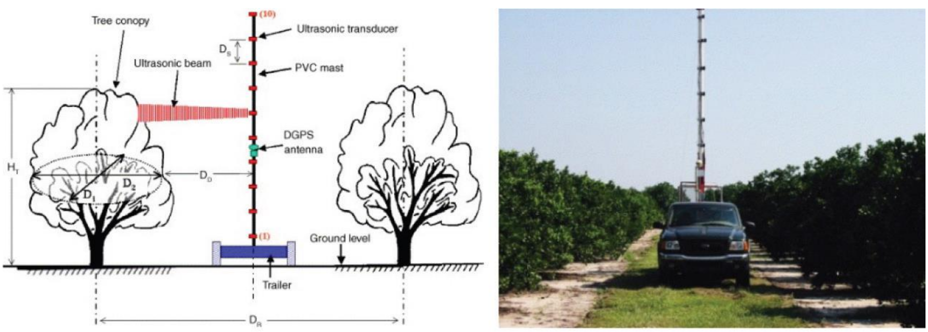


Figure 6. Sampling strategy for one replication in the olive orchard trial (Solanelles et al., 2006)

A variable-rate sprayer (Figure 7) vineyard prototype was designed, implemented, and validated by Gil et al. (2013). With the help of an algorithm based on canopy volume and inspired by the tree row volume model, this prototype can adjust the sprayed volume application rate in accordance with the target geometry. The goal of this process is to maintain the sprayed volume per unit canopy volume. Variations in canopy width along the row crop are electronically measured using multiple ultrasonic sensors mounted on the sprayer and used to modify the emitted flow rate from the nozzles in real time.

Figure 7. (a) and **(b)** Placement of components on the sprayer, **(c)** laptop for wireless control of the prototype from the tractor cab, **(d)** interface for input data created using LabVIEW (Gil et al., 2013)

A software for real-time ultrasonic mapping of tree canopy size was created by Schumann and Zaman (2004). The ultrasonic transducer system schematic layout and manually measured tree dimensions were utilized to compute the tree canopy sizes within a citrus grove. Tree heights and volumes were measured using a vehicle and trailer equipped with a differential global positioning system (DGPS) and a vertical array of ten ultrasonic transducers. Transducers are positioned between 0.6 and 6.0 meters above the surface (Figure 8). A grove of 376 citrus trees was surveyed twice using this automated system to assess repeatability, and the results were compared with manually measured size data of 30 trees to estimate accuracy. The volume and height of the trees, which ranged from 6.3 to 54.0 m^3/tree, and their manually measured and ultrasonically measured counterparts did not significantly differ, according to the results. For GIS mapping purposes, the system located tree positions 95% of the time within 1.37 m.



(a) (b)

Figure 8. (a) Schematic layout of ultrasonic transducer system, **(b)** vehicle and trailer with vertical array of 10 ultrasonic transducers

A real-time technique for estimating canopy density in apple orchards and vineyards was proposed by Palleja and Landers (2015), and is based on an array of ultrasonic sensors (Figure 9). Two sets of experiments were conducted. In the first, the signal behavior and algorithmic adjustments were made in a greenhouse using a single ultrasound sensor. Under actual working conditions, the second set of experiments was carried out in the vineyard and orchard. The signal obtained is highly correlated with the growing season, according to the results, and it has similar values on both sides of the row, with an error of 3.8%

in apple trees and 14.1% in vineyards. It is also sensitive enough to detect the effects of hailstorms on the canopy.

(a) (b) (c)

Figure 9. (a) Schematic hypothesis diagram, **(b)** and **(c)** modified sprayer and ultrasound sensor distribution (Palleja and Landers, 2015)

LIDAR sensor-based detection technology

LiDAR is a popular remote sensing method that employs light in the form of a pulsed laser to detect and categorize objects. LiDAR sensors generate precise, 3-dimensional information about the shape of surrounding objects and their surface characteristics. The technology uses laser beams within the eye-safe range to create a 3D representation of the surveyed environment. Typical applications of LiDAR sensor comprise surveying, geography, atmospheric physics, and archeology, but today it is used in many state-of-the-art applications as well as robotics, smart cities, autonomous vehicles and agricultural equipment.

LiDAR is an acronym of ***Light Detection and Ranging***. It is also known as laser scanning or 3D scanning. A LiDAR sensor that scans the surroundings and illustrates them in a virtual 3D format primarily consists of a laser source for shooting out laser pulses, a scanner for deflecting the light upon the scene, and a detector for collecting the reflected light. Other supporting elements are, for example, optical lenses

A typical LiDAR sensor follows a simple principle, also known as the time of flight principle. It sends out pulsed light waves into the surrounding environment, and these pulses reflect or bounce off objects and return to the sensor's detector. The time taken for each pulse to return can be used to calculate the distance it traveled

Laser emits light pulses and detects the light reflected by the objects. The sensor measures the time between the emission and return of the laser pulse (echo). The distance is then calculated using the velocity of light using the formula shown in the figure below (Figure 10).

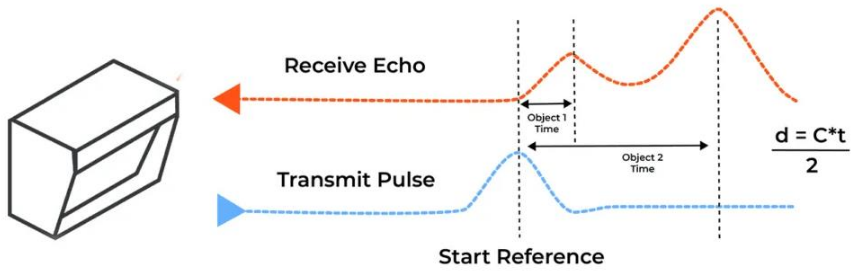


Figure 10. How LiDAR calculates the distance from objects. D = distance, C = speed of light, t = time taken for pulse to travel to the object and back to the receiver

When paired with a scanning mechanism, the measurement beam of laser light is thinner and less divergent than that of ultrasonic waves, which makes it advantageous for reporting data covering a wide area in a bidimensional scan pattern (Wehr et al., 1999). These days, canopy structure is characterized using terrestrial LIDAR for a variety of uses, including forestry and agriculture. The volume of the trees in an orchard can be measured thanks to the application of terrestrial LIDARs in agriculture. The capacity to measure the distance between a sensor and its surroundings at a rate of thousands of points per second allows us to generate 3D cloud points, which, when combined with the right algorithms, allow us to accurately reconstruct and describe the structure of trees digitally (Gorte et al., 2004). For these reasons, LIDAR systems have become one of the most popular sensors for the geometric characterization of tree crops, even though they are limited to dusty environments. One key component of vegetation structure that LIDAR's ability to measure is spatial variations, which is a major improvement over some earlier techniques. LIDAR systems can be used to measure canopy structure changes over a range of time scales, allowing for the provision of comprehensive evaluations of how the canopy grows and responds to field experiments. It is imperative to fully explore LIDAR structural applications since laser technology provides unique alternatives for the viewing angle and distance data required to model canopy structures (Van der et al., 2006). The creation of the LIDAR system allowed for the acquisition of 3D digitalized images of crops, from which a substantial quantity of plant data, including height, width, volume, leaf area index, and leaf area density, could be extracted.

However, two-dimensional (2D) terrestrial LIDAR sensors can be used in agricultural applications; these sensors are significantly less expensive to use (Walklate et al., 2002). A point cloud corresponding to a plane or portion of the object of interest is obtained by 2D LIDAR sensors. These sensors' one-plane scanning limitation does not always mean that 2D perception is the only thing they can detect (Rovira-Más et al., 2006). Therefore, this sensor outputs a point cloud that can be used to create a 3D image through post-processing. The use of a 2D LIDAR scanner in agriculture to obtain 3D structural characteristics of plants was suggested by Rosell et al. (2009). The outcomes for citrus orchards, fruit orchards, and vineyards demonstrated that this method could produce quick, accurate, and nondestructive 3D estimates.

A 2D LIDAR scanner technique was proposed by Rosell et al. (2009) in agriculture to obtain 3D structural characteristics of plants (Figure 11). The physical characteristics, morphology, and overall look of the 3D digital plant structure and the actual plants showed a high degree of agreement, demonstrating the coherence of the 3D tree model created from the developed system in relation to the actual structure. The correlation coefficient between manually measured volumes and those derived from the 3D LIDAR models was as high as 0.976 for a subset of trees.

(a) (b) (c) (d)

Figure 11. The LIDAR measurement system, **(a)** data in Cartesian coordinates, **(b)** data in polar coordinates, **(c)** pear orchard, **(d)** different views of the 3D structure (Rosell et al., 2009)

Escolà et al. (2013) created, put into practice, and verified a prototype (Figure 12) that uses a variable-rate algorithm to continuously and real-time adjust the volume application rate to the canopy volume in orchards. The actuators, the controller running a variable-rate algorithm, and the canopy characterization system (using a LIDAR sensor) comprised the three components of the orchard prototype. By converting canopy volume into a flow rate using an application coefficient—the necessary liquid volume per unit of canopy volume—the controller ascertains the desired flow rate. Electromagnetic variable-rate valves are used to control the sprayed flow rates. The prototype aimed to maintain the actual application coefficients as near to the target as feasible. There were strong connections found between the sprayed and the intended.

Figure 12. Variable-rate orchard sprayer prototype implemented with LIDAR sensor (Escolà et al., 2013)

Stereo vision-based detection technology

Stereo imaging is a passive measurement technique that enables distance calculation by combining images obtained from different points with two cameras. In the stereo imaging technique, the two images obtained are first corrected and combined. A displacement (disparity) map is created from the combined image and depth (distance) calculation is made.

There are two ways to measure the distance of an object from the camera. Active measurement means measuring the distance of an object by sending signals such as microwave, sound wave, infrared or laser to the object. Passive measurement, on the other hand, is the evaluation of existing information without sending any signals to the object itself.

Stereo imaging is a passive measurement technique that enables distance calculation by combining images obtained from different points with two cameras (Ozluoymak et al., 2020).

Active measurement only gives the distance of the object to the sensor. In passive measurement, it is possible to extract the geometry of the object as well as its distance.

In the stereo imaging technique, the same object is imaged from two different camera positions. The position of the object is determined on both images. The distance between objects (pixels) is inversely proportional to the distance between the camera and the object. The human eye uses similar technique to obtain depth and distance perspective.

In the stereo imaging technique, the two images obtained are first corrected and combined. A displacement (disparity) map is created from the combined image and depth (distance) calculation is made. High displacement means the object is closer to the camera. Low disparity indicates that the object is further away from the camera. Three-dimensional reconstruction is performed using displacement and camera calibration parameters.

The software processing steps in stereo imaging are as follows.

- Object Detection
- Image Compositing
- Displacement (Inequality) Map
- Depth (Distance) Calculation
- 3D Reconstruction

By checking the distance of an object moving towards or against the camera more than once, the movement speed of the object can be calculated. The greater the number of controls, the greater the measurement accuracy will be.

Cameras with high resolution and high processing performance should be used to minimize artifacts in matched video frames.

Studies on the stereo imaging technique show that the margin of error in distance measurement has decreased to 3 percent. This is an acceptable ratio for distance and speed measurement in various applications.

Stereo imaging technique is widely used in robotics industry, autonomous vehicles, traffic systems, smart city applications to improve measurement accuracy and accelerate real-time distance measurement.

In agriculture, Using video processing techniques, a camera can record video images of fruit trees and separate parameters like height, density, and the area of the leaf wall based on color information. However, distance can only be estimated using the precalibrated distance from the video camera due to a lack of measured distance information, which can easily result in relatively large errors. With a digital camera that uses a CCD or CMOS image sensor, computer stereo vision refers to the process of extracting three dimensions from digital images. A binocular camera can be used to combine two simultaneous monocular field photos to create a three-dimensional field image (Kise et al., 2005).

For an autonomous, selective vineyard sprayer, Berenstein et al. (2010) suggested grape clusters and foliage detection algorithms (Figure 13). In order to minimize the amount of pesticide used when spraying foliage, new machine vision algorithms were created to identify the spaces between grapevines and to pinpoint the precise location of grape clusters so that spraying can be directed toward them. The amount of spraying material and labor required would be greatly reduced if a spraying robot with these detection capabilities and a pan/tilt head with a spray nozzle could spray precisely and selectively. The results indicate that grape clusters can be detected with 90% accuracy, which reduces the need for pesticides by 30%.

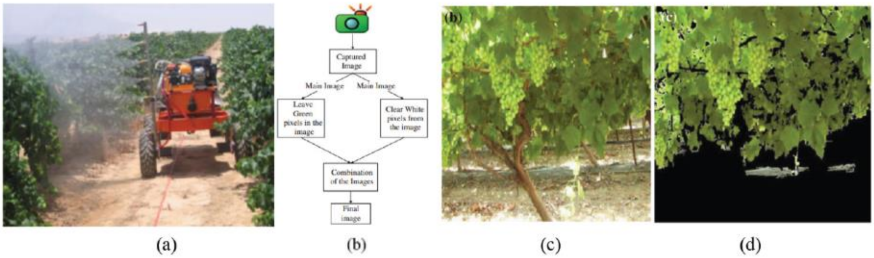


Figure 13. **(a)** Vineyard spraying robot, **(b)** block diagram of the algorithm, **(c)** captured image, **(d)** final foliage image

Based on the depth-of-field extraction algorithm, Xiao et al. (2016) developed an intelligent precision orchard pesticide spray technique (Figure 14). The benefits of color and depth information were combined with Microsoft's Kinect system to create the intended spray effect. An equation for determining the leaf wall area average distance of fruit trees was proposed, with the goal of allowing sprayers to be adjusted and controlled in terms of both spray intensity and pesticide dosage. The distances computed using the Kinect system's data were accurate, as demonstrated by a comparison with the measured distances. The study conducted on peach, apricot, and grapevine trees revealed that the intelligent orchard pesticide precision spray model, which is based on the average distance and the density of the leaf wall area, can enhance pesticide application efficiency, minimize waste and pollution to the environment, and accomplish automated and precise orchard production.

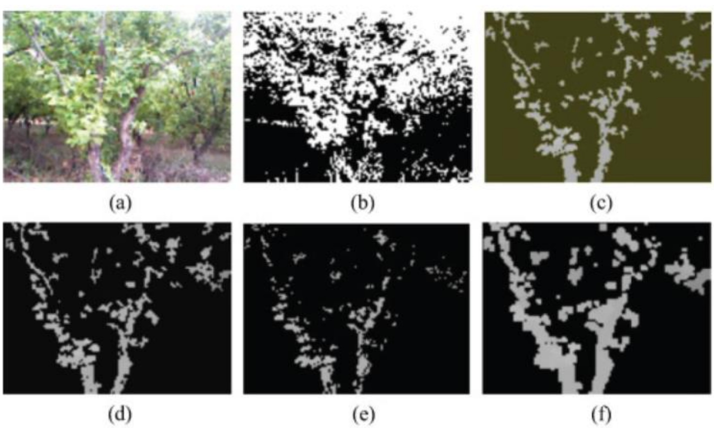


Figure 14. The procedure of target tree extraction. **(a)** Color image, **(b)** segmented image, **(c)** depth image, **(d)** 3D layer in-depth image, **(e)** comparative image, **(f)** resultant image

Real-time sensor technologies used for variable rate applications in pesticide application are summarized comparatively in Table 1. Table 1 presents a summary of the main benefits and drawbacks of the exposed sensors and methods for measuring the geometrical properties of crops and plants, based on findings from reports and literature.

Table 1. Physical principles and most remarkable characteristics of the main systems used for the geometrical characterization of tree crops and their main advantages and disadvantages (Zhang et al., 2018)

Sensors	Measuring principle	Pros	Cons
Infrared sensors	All objects with a temperature above absolute zero emit heat energy in the form of radiation. Infrared sensors measure infrared light radiating from objects in their field of view. Work entirely by detecting infrared radiation emitted by or reflected from objects.	Temperature and humidity have little impact on the detection results. Measurement relatively independent of atmospheric conditions.	Accurate measurement of the 3D characteristics of the canopy remains unfeasible for the moment. Plant appearance, light intensity, walking speed, and plant space have evident influences on detecting effect. Deficient spatial resolution for applications in agriculture. Short detectable distance, complicated circuit.
Ultrasonic sensors	Measure the distance to an object by using sound waves. Based on determining the flight time of an ultrasonic wave from the point of emission to the point of detection after bouncing off an object.	Robustness and low price make ultrasonic sensors suitable for agricultural applications. Relatively easy to implement.	The large angle of divergence of ultrasonic wave beams limits the resolution and accuracy of the measurements taken. The use of many units to cover a common agricultural scene is required.
LIDAR sensors	Based on the measurement of the distance from a laser emitter to an object or surface using a pulsed laser beam. Time-of-flight LIDAR measures the time that a laser pulse takes to travel between the sensor and the target.	High speed of measurement allows obtaining cloud points quickly. Applying appropriate algorithms makes it possible to digitally reconstruct and describe the structure of trees with high precision. Plant information, such as height, width, volume, leaf area index, and leaf area density can be obtained with sufficient precision.	The estimation of the volume is very sensitive to errors in the determination of the distance from the LIDAR to the center of the trees and in the determination of the angle of orientation of the LIDAR. Motorized terrestrial LIDAR scanners must include additional devices or procedures to control or estimate and correct these error sources.
Stereo vision	Provides a 3D field image by combining two monocular field images taken simultaneously using a binocular digital camera. Computer algorithms are necessary to convert the original camera coordinate arrays of the objects into their real-world coordinates.	Provides realistic 3D image of plants and tree crops. Measures directly the 3D vegetation structure including those plant physical parameters that are important for production management, such as crop size and volume.	Offer less accuracy than laser-based systems and need appropriate calibration and recording procedures. When several images are processed together, the magnitude of the data files grows considerably, complicating the handling and storage of 3D information and requiring long processing times. The problem becomes more critical when real-time processing is required.

CONCLUSION

Innovative techniques are crucial in improving the performance of variable-rate sprayer application in agricultural applications. Precise tree canopy characteristics can be detected by the various sensing systems, and when paired with advanced decision-making models, they allow for precise variable-rate sprayer dosage control. Future goals for this research line include the coordinated use of multiple sensors, the creation of new real-time data processing algorithms, and the simplification of crop adaptable application systems. The evolution and development of new sensors dedicated to the geometric characterization of tree crops will soon allow for much-needed advancements in training system improvement and production and quality increases by optimizing the use of variable-rate sprayers in agriculture. It is important to remember that the advantages of variable spray apply to millions of cultivated hectares, which directly affects our environment and society.

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CHAPTER III

ARTIFICIAL POLLINATION APPLICATIONS IN FRUIT TREES

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INTRODUCTION

During the flowering, pollination and fertilization periods of fruit trees, problems are experienced in pollination and fertilization due to global climate change, temperature increases and irregularities in the precipitation regime. Heavy rains or extreme temperature increases, especially during the pollination period, cause significant fruit losses in trees. At the same time, the decrease in global pollinators in the environment and changes in land use lead to the restriction of pollination, which will have negative consequences for agricultural productivity (Wurz et al., 2021).

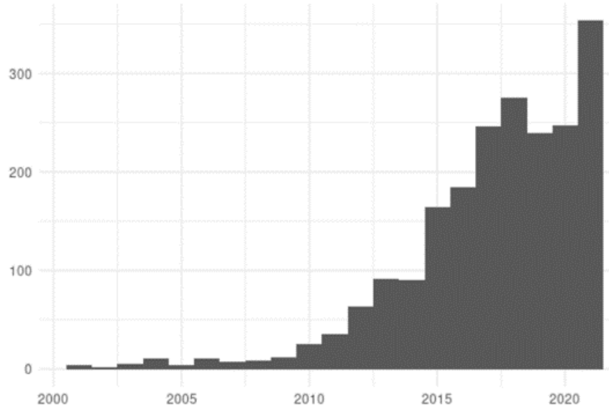
As it is known, in garden plants with monoic and dioecious flower structures, andrecheum and gyneceum are spatially found either in separate flowers on the same plant (monocious) or in different plants (dioecious). In dioecious fruit species such as kiwis or pistachios, staminate and pistillate flowers are produced on different plants, preventing self-pollination. In monoecious fruits such as walnuts or some dates, self-pollination is difficult but not completely prevented. In the case of dichogamy, there is a temporal separation between the maturation of male and female organs in flowers of the same plant, so cross-pollination can occur between plants with male and female flowering stages occurring at the same time (Bertin and Newman, 1993). For example, in species with protogenic (female flowers bloom first) and dichogamous species (walnuts, chestnuts), such as avocados, the female organs mature earlier than the males; Since pistachio has a dioecious (dioecious) flower structure, if the male does not get enough pollen during the flowering period, fruit set cannot occur because there is no pollination. This situation causes significant efficiency loss.

A pressing issue facing the agricultural sector today is the decline of natural pollinators, especially honeybees. Many farmers pollinate plants by natural pollination. However, this method alone is insufficient and does not pollinate effectively. To this end, farmers often rent and transport bees and bring in bees from elsewhere to provide pollination services. However, this increases the cost to farmers. Therefore, there is a need to develop alternative pollination to solve the problem (Ohi et al., 2018). Pollination doesn't happen reliably enough by natural means, so it is needed to artificially pollinate each female palm to sustain yield levels, enhance fruit set and make the production economically feasible for date farmers (Jameela and Alagirisamy 2021).

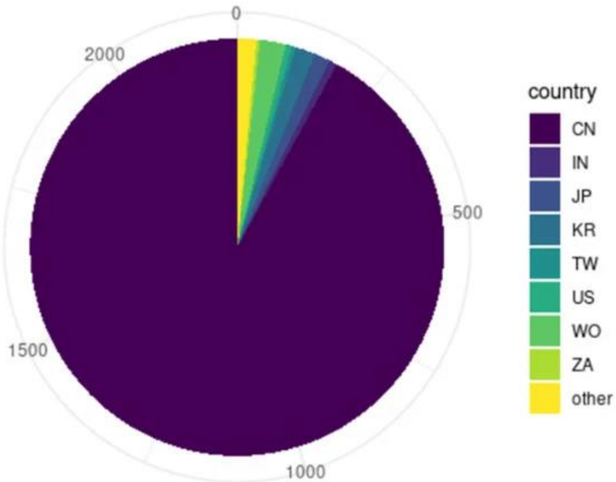
Pollination in fruit trees is critical for yield (. The demand for artificial pollination systems in fruit growing is increasing due to the need for both insect and wind-based pollination and the problems experienced in the simultaneous flowering of pollinator varieties with the main variety due to adverse climatic events. That's why pollination technology is developing more and more. Artificial pollination devices, formerly manual pollination, hand-held and backpacking devices, vehicle-mounted devices, unmanned aerial vehicles (UAVs), and robotic and autonomous pollinators, are constantly being developed. In recent years, these systems have been carrying out effective and local pollination in plants such as pistachio, almond and walnut, generally using pollen as a system input.

Wongnaa et al. (2021), analyzed the impact of the adoption of artificial pollination on productivity, income, poverty and food security among cocoa farmers in Ghana. Primary data were collected from 206 cocoa farmers drawn through a multi-stage sampling technique and analyzed using Propensity Score Matching. The study found that households that adopted artificial pollination experienced improvements in productivity, income, poverty status and food security. In addition, they revealed that producers who use artificial pollination increased their products by nearly 15.34% on average, earned more in terms of income, and reduced their poverty by an average of 0.83% to 3.53%. It has been stated that steps should be taken in the implementation of artificial pollination to benefit from the positive impact of the adoption of artificial pollination.

A high-quality pollen source and available pollen harvest are required for most artificial pollination technologies to be successful. However, collecting pollen and applying it is limited in time and physically and problems arise. Despite these limitations, in the last decade, many researchers, as well as small and newly established companies, have developed artificial pollination devices to solve the pollination problem, and patent applications have been made for these devices. The graphs in Figure 1 show the number of patents for artificial pollination by year (a) and their distribution by country (b).



(a)



(b)

Figure 1. Number of artificial pollination patents (a) and their distribution by country (b) (Broussard et al., 2023)

(Countries are listed by their two-letter code, in order; China, India, Japan, Korea, Taiwan, United States, "WO" is worldwide patents, South Africa, and "other" represents an additional eleven countries)

As can be understood from here, artificial pollination constitutes a significant problem in the world and studies are being carried out in many countries to develop devices that increase artificial pollination.

Pollination is the key process in fruit production, and adequate and well-distributed pollination can help to increase outputs and improve quality. In recent years, artificial pollination has been widely used in fruit production, which is labour intensive, low productivity and process limited, and cannot adapt to large-scale production. Therefore, to take full advantage of pollen, the technique and machinery used for pollination is needed (Ding et al., 2015).

Artificial pollination by contact is the transfer of pollen from the male organs of the flower to the flowers on the female tree. This application can be done dry and wet. For dry and wet artificial pollination, it is necessary to collect pollen and transfer it to the female tree with a dispenser. The advantage of dry application is that the pollen remains alive longer. On the other hand, in wet application, a larger mass mixture is provided, which provides more control (Pinheiro et al., 2023)

These; pollination with manuel, pollination with vehicle-mounted devices, Unmanned Aerial Vehicles (UAV), Electrostatics in artificial pollination and Robotic pollination methods.

Manuel Pollination Method

In this method, feather brushes and cotton cloth bags are used. The mixture (flour + pollen) placed in the bags is attached to the end of a stick and applied to the trees with the help of workers, as seen in Figure 2 (Onay et al., 2012). Although this method creates a greater pollination effect than natural pollination, it has disadvantages such as high labour requirement, inability to pollinate a sufficient area in a limited time, and high application cost.

Figure 2. Hand pollination application method (Anonymous, 2023a)

The most basic pollination process is manual pollination based on human labor. This method of pollination is very time consuming, labor intensive and quite expensive. This type of artificial pollination can be profitable and advantageous in three different situations: (i) self-compatible crops, (ii) crops where the cost of pollen is low, and (iii) crops where the market value of the crop is very high (Pinheiro et al., 2023)

Mechanical Pollination Method

Mechanical pollination devices have been developed for areas with higher tree crown heights where Hand Pollination Method is difficult (Khatawkar et al., 2021). Atomizers (Figure 3), vibrating wands, electric brushes, and leaf blowers are used in this process. These devices generally have a unit consisting of light metal or plastic pipe to reach the target and reduce the burden on the operator.

Figure 3. Motorized atomizer used in pollination (Anonymous, 2023b)

Dingley et al. (2022) noted that methods used by growers to artificially pollinate tomatoes include trellis guides, vibration probes (tuning fork/vibration bar), and air guns, and vibrating probes can be used to shake the staminal cone to allow pollen to be expelled (They stated that artificial vibrating systems increased fruit weights by 10-17% in open field systems and fruit yield by 75% in greenhouse production, compared to controls without application).

Unmanned Aerial Vehicles (UAV) Pollination Method

As the honey bee population and natural pollination effect continues to decrease with environmental pollution and climate change worldwide, people are turning to artificial pollination. Since there is an intense labour requirement in artificial pollination, today, artificial intelligence, ground positioning systems (GPS) and UAV robots have started to perform these operations. With the integration of the UAV camera and pollinator unit, artificial pollination is carried out by carrying pollen. Pollination is carried out using wind energy produced from UAVs instead of direct contact. Some recent studies show that the wind field created by the UAV has a positive effect on pollen distribution (Silva and Piyasena, 2022).

UAVs can follow the path in a certain order on the row in orchards. This process can be provided directly by a pilot or autonomously. Here they take a standard approach and use a 3D model of the environment. UAVs used in pollination are modifications of commercially available ones designed for agricultural chemical spraying. However, some are also designed specifically for pollination applications (Broussard et al., 2023). For example, Mazinani et al. (2023) produced an aerial vehicle (UAV) for artificial pollination of walnut trees. With the UAV produced, pollen was deposited on walnut trees. For this purpose, a tank with a new pollinator unit was designed (The tank is made of polyethylene). The lid under the tank is opened and closed using a servo motor and the pollen falls from there (Figure 4). In addition, the air flow under the UAV propellers collects pollen using fluid dynamics (CFD) software. The effect of flow was examined.

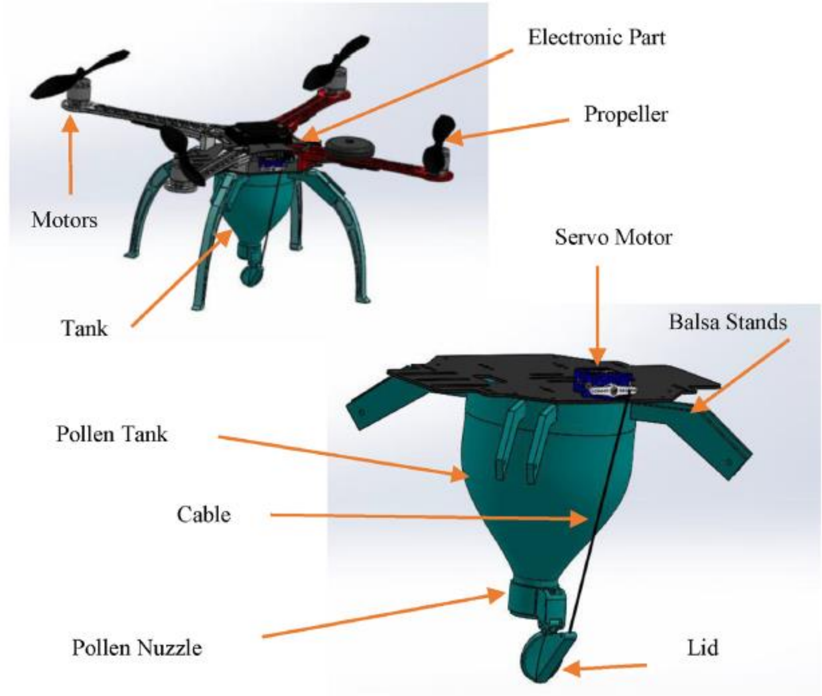


Figure 4. Schematic view of the UAV design developed for walnut tree (Mazinani et al., 2023)

When the best results obtained were compared, it was determined that the designed UAV achieved a 134.7% increase compared to traditional manual dusting. Based on these results, it has been demonstrated that it can be widely used in artificial pollination with future UAV systems. Rehna and Inamdar, (2022), applied pollination with UAV on date palms (Figure 5). They stated that the number one advantage of this method is that it is extremely fast, pollinating a palm tree by hand takes 20 to 30 minutes, and pollinating a farm of 50 trees will take 20 to 25 hours. However, they stated that since the pollination time of a palm tree with UAV takes as little as 4 to 20 seconds, the pollination time can be saved significantly. They stated that there was no significant difference in the quality and quantity of fruits produced compared to the traditional method. It has been stated that the UAV will have the ability to scan many farms within a few hours.

Figure 5. Pollination application with UAV on date palm (Rehna and Inamdar, 2022)

In addition to the speed advantage in dusting applications with UAV, it provides many advantages in terms of manoeuvrability, speed, safety and correct application. These advantages can be achieved with GPS (Global Positioning System), HD (High Resolution) camera systems and other data collection devices that assist subsequent product management. stated.

Robotic Pollination Method

Autonomous robotic pollinators are often designed to target individual flowers to minimize waste. Generally, machine vision is used to identify a flower that requires pollination. In general, two approaches to delivering pollen have been investigated in this system: bringing an end effector closer to the flower or spraying pollen from a distance. In this context, various methods have been investigated, such as using a robotic arm to fill the flower with pollen, touching the flower with a vibrating bar, or applying pollen by vibration or air blowing.

In this method, the idea of using robots as pollinators has started to gain popularity in recent years due to the decrease in bees. Researchers are investigating the design and control possibilities of small, insect-like flying robots. For this purpose, quadcopters that can pollinate flowers have also been developed. Although the feasibility of robotic pollination is still at an early stage, it shows significant potential.

A sensitive robotic pollination system developed by Virginia University has been developed (Figure 6).

Figure 6. Precision pollination developed by Virginia University (Ohi et al., 2018)

With the design of an autonomous robot, a robot called "BrambleBee" has been produced, aiming to pollinate plants. The robot works in a greenhouse environment and behaves similar to the behaviour of bees. The latest technologies are used for robotics, location, mapping, visual perception and path planning.

Artificial pollination is very costly for most growers due to high labour requirements and inefficient use of expensive pollen. Williams et al. (2020) investigated the performance evaluation of a robotic artificial pollinator designed to provide a more efficient, reliable and cost-effective means of producing kiwifruit. According to the results obtained, it was concluded that the robot could target and pollinate 79.5% of the flowers.

Electrostatics Pollination Method

Artificial pollination requires skill and specialized equipment to collect pollen grains from the anther, drying and depositing them onto the receptive stigma without mechanical damage. Nectarless-flower plants are more susceptible to high rate of pollen loss due to insufficient pollinators and pollen-stealing visitor insects. Such species need to be protected from pollen loss and pollinated by artificial means. The role of electrostatics in natural honey-bee pollination has been explored and confirmed by researchers as a significant factor in pollen detachment in the last two decades. Scientific modelling and analysis showed that there were conceivable probabilities where the accumulated charge on a honey bee was capable enough to detach pollen without physical contact. The average vertical electric field could be 100–150 V m^{-1}, while ground surface carried negative charge and air possess equal and opposite positive charge. As the plants are grounded to earth, they carry negative charge, but this charge is found to be uneven on the plant body, especially concentrated near the tips and spiked portions. Studies on application of electrostatic pollination technique have been carried out for wind-pollinated crops like date palm, which showed significant rise in fruit set due to increased deposition of charged pollen, while reporting less amount of pollen required to pollinate sufficiently (Khatawkar et al., 2021).

RESULTS

Artificial pollination is used in many crops to achieve a greater number of pollinated flowers, greater uniformity in fruit shape, and more regular production. In this article, the importance and details of artificial pollination are analyzed by examining the latest developments in the field of artificial pollination, from manual pollination to robotic pollination. Most artificial pollination research to date treats efficiency as the final outcome, regardless of pollen transport from trees. However, pollen powder produced from male trees is available in limited quantities and cannot be produced sufficiently by natural pollination. However, artificial pollination practices, especially in orchards, play an important role in the agricultural system and are becoming an increasingly important element. For this reason, in recent years, various research activities have been initiated and new technologies have begun to be developed on the collection, processing and management of pollen for artificial pollination in orchards.

Various devices for crop pollination are already in commercial use and are being developed with an increasing emphasis on robotics-based solutions. The higher the precision in the process, the less pollen is wasted and the better the yield. The shorter the operating time in pollination, the greater the likelihood of large-scale propagation. However, the increase in research and development of commercial solutions indicates increasing recognition of the vital role of pollination in agricultural food production. In this context, there is a need for new R&D studies and the development of technological applications such as robotic and autonomous pollinator systems.

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CHAPTER IV

BIOSENSOR APPLICATIONS IN AGRICULTURE

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INTRODUCTION

Biosensors are defined as analytical devices that incorporate a biological sensor and are combined with a physicochemical transducer. A biosensor essentially consists of a bioreceptor, a transducer, and an electronic component. While various biomolecules such as enzymes, nucleic acids, microorganisms, organelles, and antibodies are commonly used as bioreceptors, electrochemical electrodes, optical fibres, transistors, thermistors, and piezoelectric crystals are frequently employed as transducers (Boz et al., 2017). Biological sensing elements connected to a transducer in biosensor technology convert observed responses into measurable electrical signals as shown in Figure 1 (Verma and Bhardwaj, 2015).

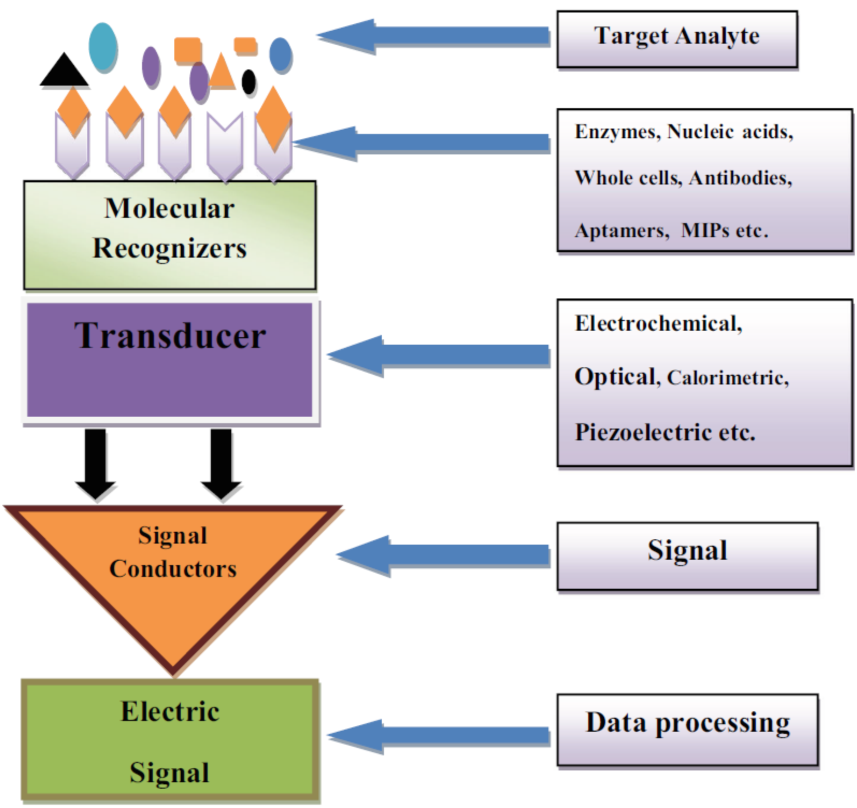

Figure 1. Basic layout of elements of biosensor for its construction (Verma and Bhardwaj, 2015)

Biosensors enable the analysis of samples that would typically require lengthy tests to be performed more quickly. Biosensors allow for the rapid diagnosis of diseases, quality control of foods, detection of pesticides or toxins, measurement of organic pollutants in water, and the quick detection of toxic substances, heavy metals, and pathogens.

The concept of biosensors was first invented in the 1950s by L. C. Clark for oxygen detection (Bulut, 2011). The characteristics sought in advanced biosensors are outlined below (Kökbaş et al., 2013):

- **Sensitivity:** It means the device responds directly to changes in the analyte.
- **Selectivity:** The device only indicates the specificity of the analyte. The device does not react to other reagents and does not yield incorrect results.
- **Measurement Range:** It is the range of analyte concentration that the device can measure.
- **Measurement Time:** It indicates the measurement speed of the device.
- **Consistency:** It expresses the consistency in the results of the device.
- **Detection Limit:** It represents the lowest analyte concentration that the device can measure.
- **Lifetime:** It denotes the service life of the device without a noticeable decrease in performance.
- **Stability:** It is a quality measurement value that takes into account changes in the sensitivity of the device over a certain period of time.

A biosensor is an analytical device that incorporates biological sensing elements, often referred to as bio-receptors, which are either closely connected to or integrated within a transducer system. Biosensors can be classified into different categories based on the type of transducers they use. These categories include electrochemical biosensors (conductometric and potentiometric), optical biosensors (interferometric and colorimetric), mass-based biosensors (piezoelectric and acoustic wave), and calorimetric biosensors, among others (Mandal and Banik, 2021). Principle of preparation biosensor for detection is shown in Figure 2.

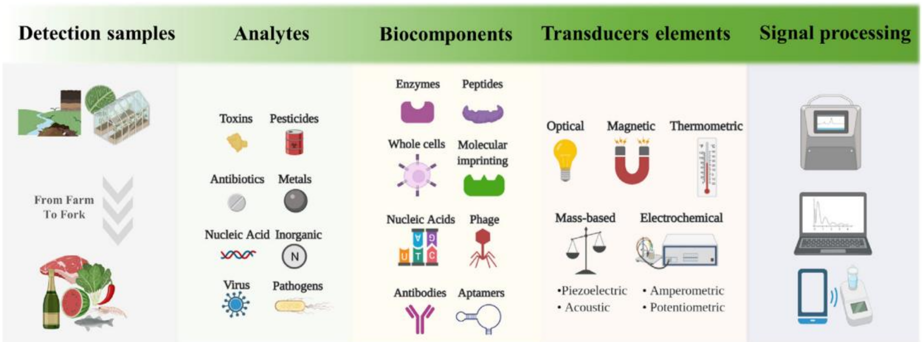

Figure 2. Principle of preparation biosensor for detection (Wang et al., 2022)

Biosensors come in different sizes and shapes, can detect and measure even low concentrations of specific pathogens, or toxic chemicals and pH levels. Various criteria are involved in the classification of biosensors and the outline classification scheme is shown in Figure 3 (Naresh and Lee, 2021).

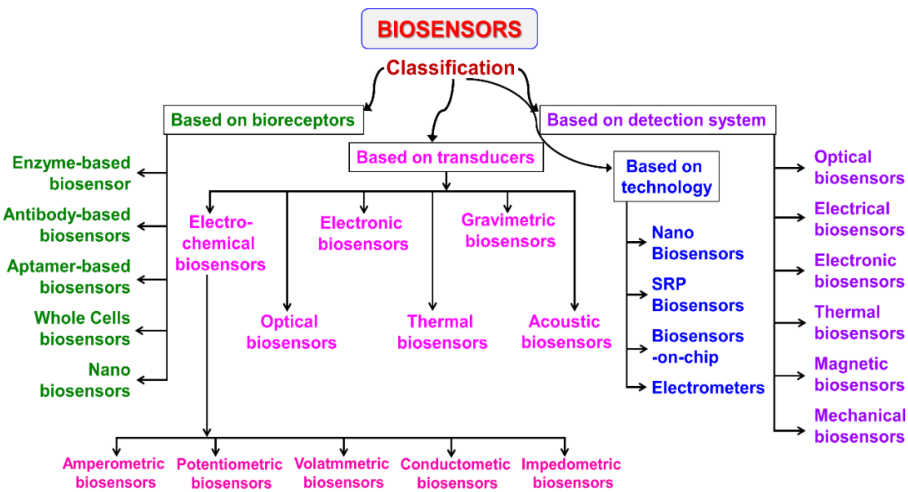

Figure 3. Classification of biosensors based on various bioreceptors and transducers (Naresh and Lee, 2021)

Also, biosensor materials and their potential applications are visually organized in Table 1 (Ramachandran et al., 2022).

Table 1. Biosensor materials and their potential applications (Mandal and Banik, 2021)

Transducer	***Biosensor type***	***Principle***	***Application***
Electrochemical	Potentiometric	Measures electric potential	Urea, CO_2, pesticide, sugar, pH determination
	Conductometric	Change in conductance	Environmental contamination, pesticide and heavy metal detection
	Amperometric	Electron movement due to redox reactions	Organophosphate pesticide, pathogen detection
	Impedimetric	Measure impedance of an electrochemical cell	Peptide, small protein, milk toxin and food borne pathogen detection
Optical	Bioluminescent	Change in luminescence	Heavy metal detection, food toxicant, pathogen study
	Fluorescence	Reaction with fluorescence tagged biomolecules	BOD measurement, water availability to plants, pathogen detection
	Colorimetric	Change in optical density	Water and food borne pathogen detection
	Surface Plasmon Resonance (SPR)	Change in refractive index from binding of bioanalytes	Livestock, disease diagnosis, drug residue testing, toxic gas monitoring
Piezoelectric	Quartz Crystal Microbalance (QCM), Surface Acoustic Wave (SAW)	Mass change in bio-components	Humidity sensor, food safety, organophosphate and carbamate pesticide detection, glucose monitoring
Thermal	Calorimetric	Heat release and absorption	Organophosphate pesticide, water and food pathogen detection

BIOSENSOR APPLICATIONS IN AGRICULTURE

Biosensors play a crucial role in medicine, food, pharmaceuticals, environmental pollution, defence, and many industrial activities, especially in automation, quality control, condition monitoring, and energy storage. Various types of biosensors being used are enzyme-based, tissue-based, immunosensors, DNA biosensors, and thermal and piezoelectric biosensors (Mehrotra, 2016).

Biosensors have a vital role in advancing both precision agriculture and sustainable farming practices. Precision agriculture, a farming management approach leveraging technology, seeks to enhance crop production efficiency while minimizing waste. As known, though chemicals are often required in agriculture to safeguard crops, droplet transportation by the air flow effect is a big problem in agriculture (Bayat et al., 2011). This involves gathering data on soil and water quality, weather patterns, and plant growth to make informed decisions regarding fertilization, irrigation and pest control.

In contrast, sustainable agriculture is dedicated to producing food while safeguarding the environment and conserving natural resources for the benefit of future generations. Biosensors contribute to this objective by curbing the reliance on chemicals and enhancing the management of water and soil resources. Biosensors have versatile applications beyond their traditional uses. They can be employed in various contexts, including monitoring crop storage conditions, detecting plant diseases, and monitoring animal health.

Biosensors are used in the diagnosis of pesticides, bad odors, artificial fertilizers, and plant animal diseases in the field of agriculture. It is widely recognized for its applications in assessing the levels of heavy metals and pesticides in soil and groundwater. Additionally, it plays a crucial role in identifying soil-borne diseases that may be challenging to address. Another significant use is its rapid detection capabilities for plant diseases, particularly those caused by bacteria and viruses. This technology finds practical applications in agriculture and dairy sectors. It is a reliable and fast option for the determination of lactose in milk. Moreover, biosensors also play a pivotal role in various applications, including assessing food quality, analyzing fundamental nutritional components, and determining parameters such as aroma and freshness. They are instrumental in detecting mutagens, allergens, and mycotoxins, as well as in deposit analysis of agricultural pesticides.

Additionally, biosensors find application in gauging the levels of additives in food and contribute to diverse fields. Beyond that, they are employed to determine the physical properties of foods, analyse the chemical components present, and quantify the presence of harmful microorganisms (Gundogdu et al., 2023).

When it comes to sustaining farming practices, the integration of new modern technologies, such as biosensors, becomes imperative. Biosensors present an affordable and highly sensitive detection solution for the agricultural and food industries. Various types of biosensors, built on the principle of converting biological signals into electronic signals, find valuable applications in agriculture.

There are some advantages of biosensors in agriculture (Jeevula and Sireesha, 2021):

- It provides precise and accurate measurements
- It is user-friendly and easy to operate
- It can also gauge non-polar molecules
- Continuous monitoring is not necessary
- It serves as a sophisticated tool for detecting and monitoring phytopathogens

The application of biosensors in agriculture enables farmers to closely monitor the environmental conditions associated with crop production, and indirect environmental monitoring is interconnected. Biosensors can be utilized for detecting a wide range of essential environmental factors, including fertilizers, moisture levels, pH levels, pathogens, herbicides, and pesticides as shown in Figure 4 (Ramachandran et al., 2022).

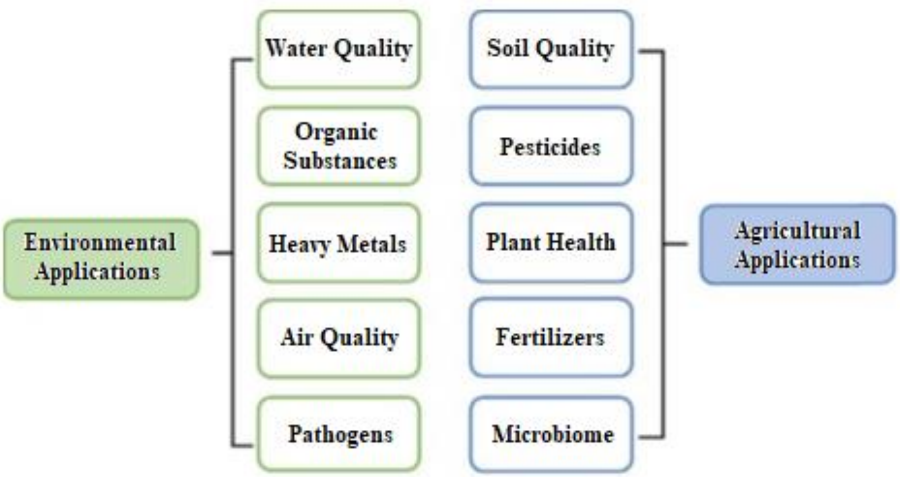

Figure 4. Biosensors for environmental and agricultural applications (Ramachandran et al., 2022)

Compared to traditional detection methods such as chromatography, these sensors offer rapid, accurate, highly sensitive, and selective detection capabilities. When combined with other technologies like GPS, they can prove invaluable for on-site monitoring of plant growth conditions, including soil moisture depletion, fertilizer level depletion, plant health, and disease detection. This data can play a crucial role in determining the optimal time for crop harvesting and calculating the precise amount of water and other fertilizers required for optimal plant growth, thereby preventing excessive use of resources. Furthermore, this approach contributes to environmental protection by reducing fertilizer leaching and water contamination, as well as curbing excess water usage (Ramachandran et al., 2022).

The agricultural sector represents a promising domain for the integration of technological advancements in biosensors. These biosensors can be systematically classified based on the transducer in environmental and agricultural applications (Ramachandran et al., 2022). Biosensors find application in monitoring the quality of soil and water to guarantee the optimal growth conditions for crops. For instance, they can measure the pH and nitrogen levels in soil, providing valuable data for optimizing fertilization practices. In water, biosensors play a crucial role in detecting contaminants and overseeing water quality to prevent crops from exposure to harmful substances.

The presence of pesticides and biological contaminants in both soil and water sources poses significant environmental and ecological challenges. Ensuring the rapid, precise, and accurate detection of pathogens and pollutants is imperative for the maintenance of soil health and the preservation of a thriving environment.

The extensive utilization of biosensors based on metals and metal oxides in soil nutrient detection can be attributed to their remarkable capacity for rapid electron transfer, electron conductivity, and electro activity (Kaushik et al., 2009). The ability of these sensors to quantify these microbial contaminations is based on accurate estimation of the oxygen consumption rate of useful/undesirable microbes in the soil (Mandal et al., 2020). Researchers claim that the utilization of aptamer biosensors for the direct detection of pesticides constitutes a highly promising alternative to conventional methodologies in the analysis of these chemical agents (Saini et al., 2017). Researchers have previously undertaken efforts to detect and quantify pesticides, including carbofuran, carbaryl, methyl paraoxon, and dichlorvos, utilizing amperometric acetylcholinesterase biosensors. The combination of both commercial and genetically modified acetylcholinesterase enzymes in amperometric biosensors has enhanced the sensors' sensitivity to these specific pesticides (Valdés-Ramírez et al., 2008). Gold nanoparticle-based microfluidic sensors, coupled with a basic digital camera as the detector, were successfully employed for the detection of the heavy metal mercury and the dithiocarbamate pesticide ziram, respectively (Lafleur et al., 2012). The application of smart nanostructured biosensors has also played a significant role in detecting soil content such as carbon, phosphorus, nitrate, potassium, and residual urea (Antonacci et al., 2018). A rapid and sensitive colorimetric method was developed to identify the nitrate in water using cysteamine modified gold nanoparticles (Mura et al., 2015). A stable solid-state electrochemical sensor was also developed for determining the total nitrogen in soil samples (Pan et al., 2016).

Plants are exposed to a wide range of environmental abiotic stress such as drought, salinity, light, heat, cold, heavy metals, and so on. Different types of plant responses against the abiotic stresses by using biosensors are shown in Figure 5 (Mondal et al., 2022).

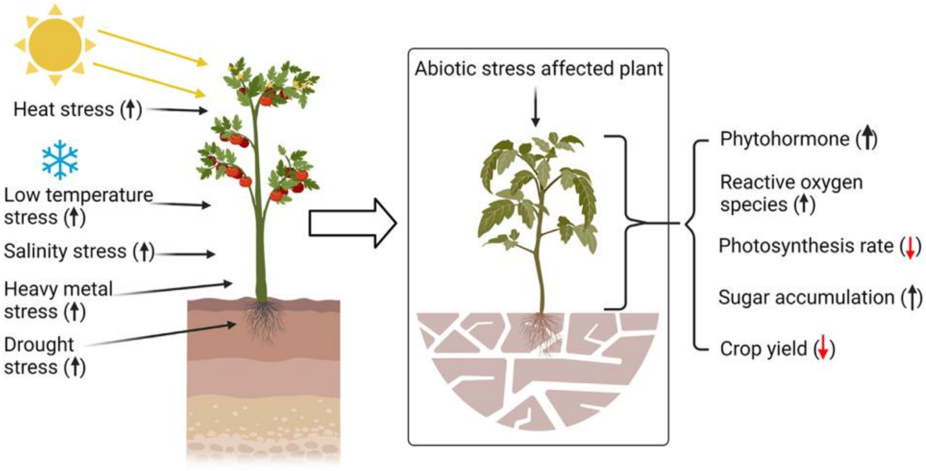

Figure 5. Different types of plant responses against the abiotic stress by using biosensors (Mondal et al., 2022)

Biosensors can serve to monitor the growth and development of crops, ensuring their health and maximizing their productivity. For instance, biosensors are capable of gauging the stress levels in plants and can direct suitable interventions, such as the adjustment of water or fertilizer levels, to optimize the overall well-being and yield of the crops.

Biosensors in agriculture are used in the field of early detection of various plant diseases such as viral and fungal infections and thereby manage and control plant health and yield (Yusof and Isha, 2020).

CONCLUSION

Biosensors are an important tool for agriculture, offering a range of benefits, including improved soil and water quality monitoring, better crop management, and more sustainable agriculture practices.

The use of biosensors in agriculture is expected to continue to grow and evolve in the future, with new and innovative uses being developed all the time. An integrated approach with combined possibilities of biosensors with other precision agriculture technologies such as nano-biosensors, robotics, and GPS systems can create smart and sustainable agricultural systems and better management of the environment. In addition, biosensors are preferred in livestock management to monitor the health of animals and improve the management of livestock production. Nowadays, the development of multi-functional biosensors is more important in order to measure multiple parameters such as pH, temperature, and nutrient levels, all in one device. Biosensors are also used in monitoring and managing food safety to provide that food products are free from pathogens and contaminants.

While biosensors can help farmers to optimize their crop management practices and reduce the chemical usage for reducing the environmental pollution and ensuring more sustainable agriculture system, they can provide real-time information for farmers to increase the efficiency about their crops.

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CHAPTER V

IMAGING TECHNOLOGIES WITH UNMANNED AERIAL VEHICLES IN AGRICULTURE

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INTRODUCTION

Although chemicals are often required in agriculture to safeguard crops, transportation of droplets by air flow is still a big problem in agriculture (Bayat et al., 2011). Additionally, climate change and environmental pollution are the main global problems of the current era and seriously affect agricultural production. Sustainable agriculture is considered one of the solutions to combat environmental pollution and reduce greenhouse gas emissions, thereby mitigating the effects of climate change. Farmers apply fertilizers, pesticides, and other agrochemicals in significant amounts without discrimination in conventional agricultural systems. Hence, there is a necessity for the adoption of clean and green technologies to carry out agricultural practices in a sustainable manner (Rani et al., 2019). The fields of electronics and mechanics have revolutionized the monitoring of agricultural fields by introducing unmanned aerial vehicles (UAVs) (Mogili and Deepak, 2020). In simple terms, an UAV, referred to as a DRONE (**D**ynamic **R**emotely **O**perated **N**avigation **E**quipment), is an aircraft capable of operating with its own power system. It can fly on a predefined route with the assistance of an autopilot and GPS coordinates without a pilot on board. Alternatively, it can be manually operated using radio signals through remote control or a smartphone application. Depending on its intended use, various equipment or payloads can be attached to its body (Evlice et al., 2022). Drones, on which many different sensors, cameras or equipment can be integrated, can obtain data more accurately and reliably in real-time. A photo of an unmanned aerial vehicle taking images for agricultural purposes is given in Figure 1.

Figure 1. Unmanned aerial vehicle taking images for agricultural purposes (Anonymous, 2023a)

Agricultural applications are currently exploring the implementation of regulated smart farming solutions, which involve the incorporation of unmanned aerial vehicles (UAVs). These UAVs integrate information and communication technologies, robotics, artificial intelligence, big data, and the Internet of Things to enhance agricultural practices. Agricultural UAVs exhibit high capabilities, and their utilization has extended across various aspects of agriculture. This includes tasks such as pesticide and fertilizer spraying, seed sowing, as well as growth assessment and mapping (Kim et al., 2019). UAVs are widely used in agriculture, especially in matters related to remote sensing, with the help of developments in imaging systems in recent years. In drone applications in agriculture, visual sensors that provide the image closest to the real image, LiDAR sensors that enable vegetation to be transported to a three-dimensional environment, thermal sensors that distinguish objects based on temperature difference, and multispectral and hyperspectral sensors that can measure reflections in the infrared wavelength are used (Türkseven et al., 2016). Although the human eye has the ability to see between 400-700 nm wavelength namely visible spectrum and cannot see outside these limits, these sensors can enable monitoring of images at different wavelengths. As shown in Figure 2, the electromagnetic spectrum covers electromagnetic waves with the frequencies ranging from below one hertz to above 10^{25} hertz, corresponding to wavelengths from thousands of kilometers down to a fraction of the size of an atomic nucleus (Anonymous, 2023b).

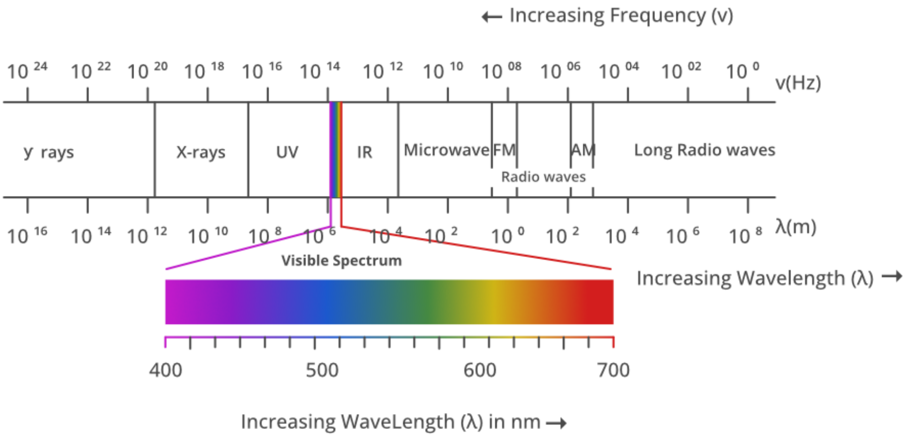

Figure 2. The electromagnetic spectrum (Anonymous, 2023c)

Spectroscopic imaging provides a promising solution for a large-scale disease monitoring under field conditions and is receiving ever-increasing research interests (Su et al., 2018).

Drones are currently emerging as a crucial component of precision agriculture, playing a significant role in promoting sustainable agriculture practices. These drones incorporate various sensors tailored to specific purposes. In agriculture, sensors sensitive to the following bands of electromagnetic waves are commonly utilized (Rani et al., 2019):

1. **Red, Green and Blue (RGB) bands**: These bands are used for several agricultural applications such as counting the number of plants, modelling elevation, and visual inspection of the crop field. By leveraging these bands of electromagnetic waves, agricultural drones enhance precision farming practices, enabling farmers to make informed decisions for optimal crop management. Red (600-700 nm), Green (500-578 nm) and Blue (460-500 nm) colors placing between ultraviolet and infrared bands are the primary colors or wavelengths of the visible spectrum as shown in Figure 3.

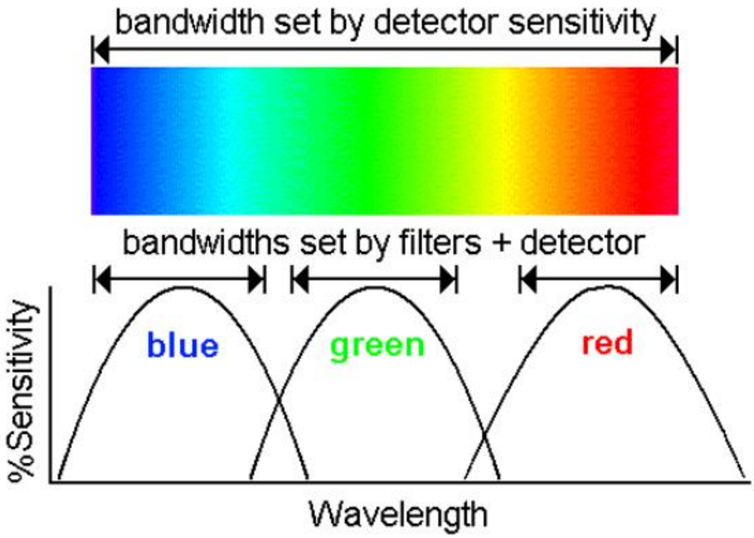

Figure 3. Three bands being used to span optical wavelengths (Anonymous, 2023d)

2. **Near Infra-Red (NIR) band:** This band is used in agricultural applications such as water management, erosion analysis, plant counting, soil

moisture analysis, and assessment of crop health. By utilizing this band for remote sensing with drones or other aerial platforms, farmers can enhance their ability to make informed decisions related to water management, erosion control, plant health, and overall crop productivity. This region is just above the visible light region as shown in Figure 4.

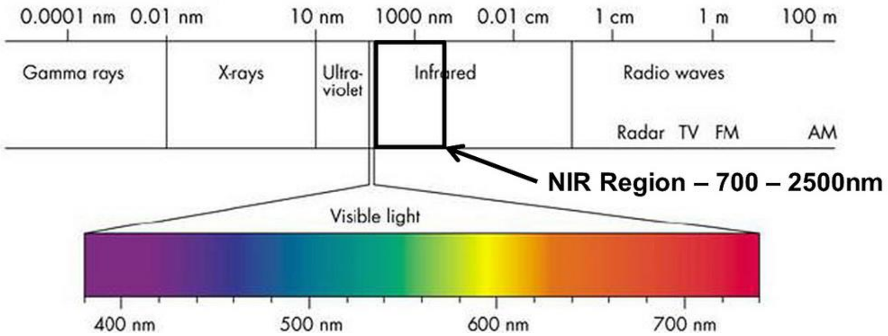

Figure 4. The Near Infra-Red (NIR) Region (Anonymous, 2023e)

3. **Red Edge band (RE):** The use of that band in agricultural remote sensing, often facilitated by drones or other aerial platforms, supports precise and efficient plant counting, water management, and assessment of crop health, contributing to improved overall farm management practices. The Red Edge band on the electromagnetic spectrum takes place between the Visible Red and Near-Infrared bands as shown in Figure 5.

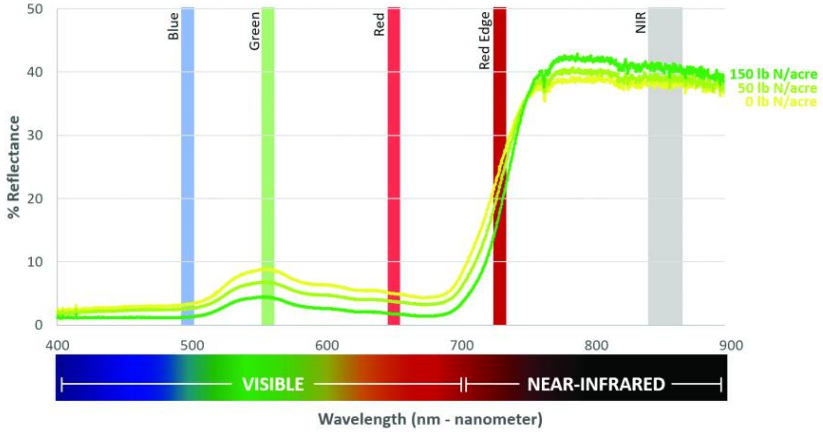

Figure 5. Red Edge region between the Visible Red and Near-Infrared bands (Thompson et al., 2017)

4. Thermal Infra-Red band: Incorporating that band into agricultural remote sensing technologies, such as drones equipped with appropriate sensors, enhances the precision and efficiency of tasks related to irrigation management, plant physiology analysis, and yield estimation in modern farming practices. The thermal infrared spectrum is divided into two primary spectra as shown in Figure 6.

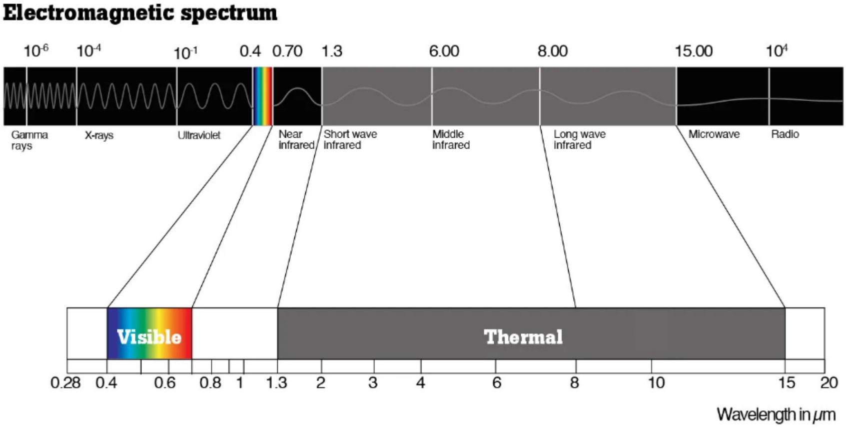

Figure 6. The Thermal Infra-Red (TIR) Region (Anonymous, 2023f)

DRONE APPLICATIONS IN AGRICULTURE

In the last decade, there have been several applications of drones in agriculture, providing real-time, more accurate, reliable, and objective data. Furthermore, the information derived from drones is in greater detail and has fewer errors. Applications of drones in agriculture are summarized as shown in Figure 7.

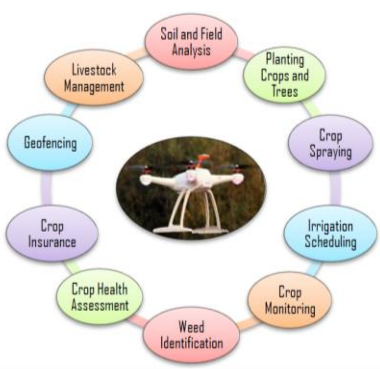

Figure 7. Applications of drones in agriculture (Rani et al., 2019)

IMAGING TECHNOLOGIES

While the number of unmanned aerial vehicles (UAVs) used in agriculture is rapidly increasing, various types platforms, controllers, sensors, and communication methods are used in the studies. Sensors are getting smarter and lighter with the evolution of technology. Nowadays, sensors with multi-spectral, hyper-spectral, RGB, and thermal cameras are used as imaging technologies in UAV applications (Kim et al., 2019). Some sensor types mounted on agricultural drones are shown in Figure 8.

Figure 8. Examples of the sensor types: (a) a RGB camera (DJI X3); (b) a multispectral camera (MicaSense RedEdge); (c) a thermal camera (FLIR/DJI ZenmuseXT); (d) a LiDAR sensor (Phoenix AL3) (Thompson et al., 2017)

As shown in Figure 9, a schematic overview of the most appropriate methods for assessing field and crop status spatially during a growing season of a wheat crop illustrates the multitude of platforms and the crucial role of UAVs.

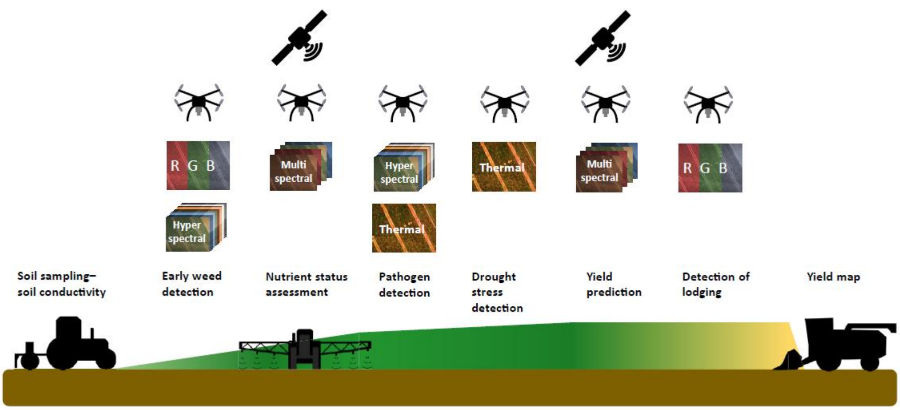

Figure 9. Schematic overview of the different ways to extract spatial information in the areas, the useful platforms and the optimal UAV sensors, throughout a growing season of a wheat crop (Maes and Steppe, 2019)

RGB Imaging

A visible camera sensor is an imager that collects visible light in the range of 400 to 700 nm, converting it into an electrical signal. This information is then organized to produce images and video streams. Visible cameras utilize the wavelengths of light between 400 and 700 nm, which align with the spectrum perceived by the human eye. Specifically designed to replicate human vision, these cameras capture light in red, green and blue wavelengths (RGB) to ensure accurate color representation in the images they create (Anonymous, 2023g). They are usually preferred in the agricultural applications because of being low cost and useful.

Similar to the human eye, visible cameras rely on light. However, their performance is significantly affected by atmospheric conditions like fog, haze, smoke, heat waves and smog. Consequently, their applications are limited to daytime and clear skies. To address this limitation, visible cameras are often paired with illumination or thermal infrared cameras for nighttime or low Lux scenarios, as well as in environments with adverse conditions like fog, haze, smoke or sandstorms that can render visible cameras ineffective (Anonymous, 2023g). The RGB image captured by a camera is segmented into red (R), green (G) and blue (B) components in order to obtain their pixel values separately as shown in Figure 10.

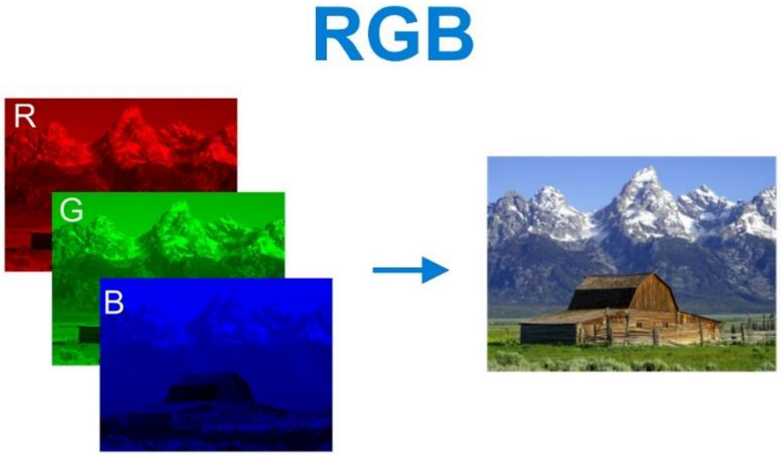

Figure 10. RGB image and its components (Anonymous, 2023h)

Multispectral Imaging

Multispectral cameras usually detect light in three to five spectral bands as shown in Figure 11.

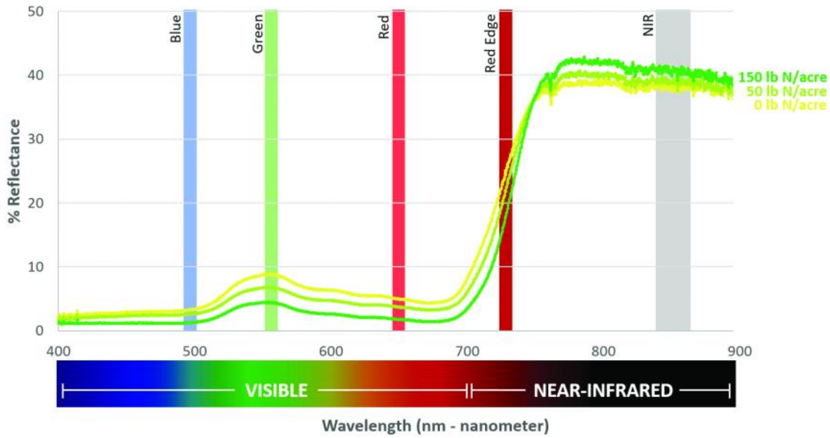

Figure 11. Spectral reflectance of healthy and stressed plants in visible and near-infrared regions (Thompson et al., 2017)

While a 3-band multispectral camera may detect light in green, red and near-infrared spectral bands; a 5-band multispectral camera may detect light in blue, green, red, red edge and near-infrared bands. The near-infrared band is in the spectral region that is not visible to the human eyes, but it is useful for detecting plant health conditions beyond the red band. Healthy plants exhibit much stronger reflectance in the near-infrared region compared to the RGB region, whereas stressed plants show decreased reflectance in the near-infrared region (Thompson et al., 2017). Multispectral cameras collect normalized difference vegetation index (NDVI) data, which can certainly aid in crop management (Knight, 2019). NDVI has become one of the most popular spectral indices for studying vegetation health and vigor as shown in Figure 12 (Olson and Anderson, 2021).

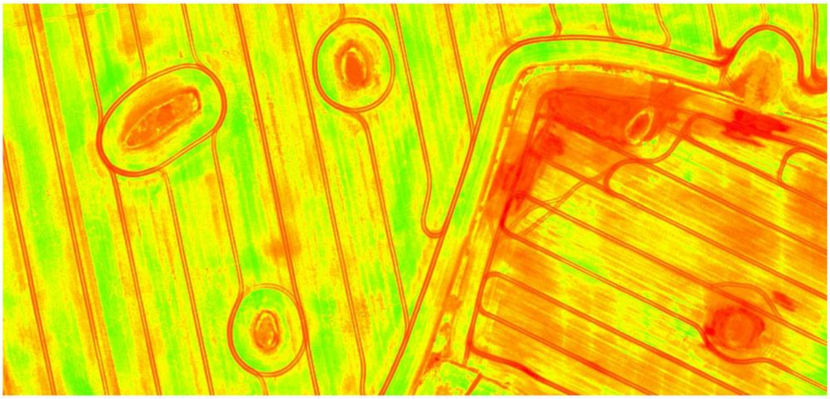

Figure 12. Normalized difference vegetative index (NDVI) unmanned aerial vehicle imagery that was captured for digital scouting. Red represents less vigorous or possible absence of vegetation; green is indicative of a lusher vegetative growth (Olson and Anderson, 2021)

Hyperspectral Imaging

While multispectral images typically display five or six bands, hyperspectral images have the capability to simultaneously process hundreds of bands. Although hyperspectral and multispectral cameras perform similar functions, hyperspectral cameras provide greater detail and precision. Multispectral cameras capture the average intensity within specific wavelength bands, whereas hyperspectral cameras measure the intensity at intervals of just a few nanometers across the entire spectrum (Knight, 2019). Figure 13 illustrates a comparison between the multispectral imaging and the hyperspectral imaging (Aboras et al., 2015).

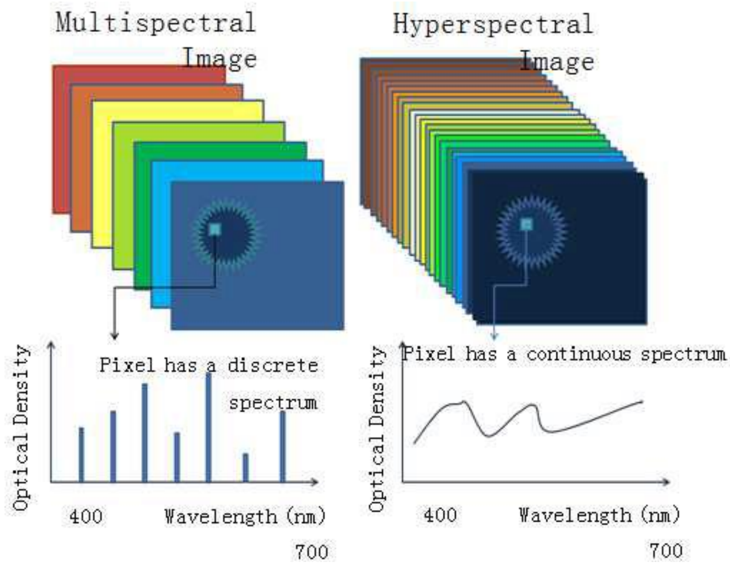

Figure 13. Comparison between Multispectral Imaging and Hyperspectral Imaging (Aboras et al., 2015)

Multispectral and hyperspectral cameras capture segments of the electromagnetic spectrum emitted from crop tissue, including the visible, near-infrared and shortwave infrared ranges (Olson and Anderson, 2021). When searching for precise reflectance, a zooming process can be employed to identify plant distress, particularly within the near-infrared spectrum. It is also feasible to differentiate between various types of trees by examining minute differences in the way light is reflected. This capability proves particularly valuable during large-scale surveys (Knight, 2019).

Thermal Imaging

In addition to RGB and multispectral cameras, thermal cameras are also utilized with drones for agricultural applications. Indeed, the principle of thermal radiation indicates that the higher the temperature of an object, the greater the intensity of emitted thermal radiation.

Thermal cameras detect radiation in the long-wavelength infrared region (8,000–14,000 nm) (Thompson et al., 2017). They can identify temperature differences in the ground, providing early indications of plant distress. This capability allows growers to intervene in the process sooner, offering them the opportunity to prevent crop loss. This technology also provides farmers with valuable information about irrigation. As the ground absorbs more water, its temperature tends to decrease. Thermal imaging captures these temperature differences, generating images that clearly indicate areas of the field with insufficient water and those with excessive water (Knight, 2019). The accuracy of thermal camera measurements is primarily affected by wind speed, ambient temperature, relative humidity, air particulates and UAV altitude (Olson and Anderson, 2021).

As an example, thermal imagery of an orange orchard captured by UAV technology for assessing water status is given in Figure 14. Cool vegetated colors are areas that are presumably water sufficient; warmer color vegetated areas are higher in temperature and may indicate the onset of water stress (Olson and Anderson, 2021).

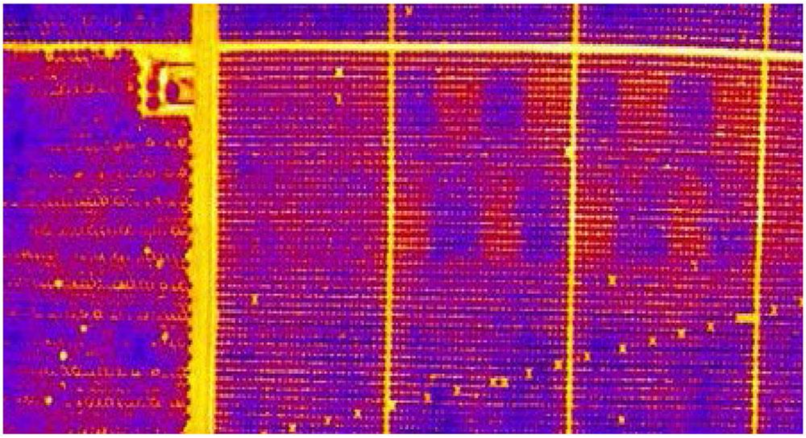

Figure 14. Thermal imagery of an orange orchard captured by UAV technology for assessing water status (Olson and Anderson, 2021)

LiDAR (Light Detection and Ranging)

A LiDAR sensor calculates the distance between itself and objects through the use of time-of-flight technology (Thompson et al., 2017). This technology utilizes laser light to generate high-resolution images capable of detecting telephone wires and penetrating through tree canopies and vegetation, revealing the terrain below. By using LiDAR technology, it is possible to capture the top of the tree as well as the leaves, the branches and the trunk to measure age and tree health. The reflective measurement capability also makes it possible to see the health of the leaves and how water is flowing for drainage monitoring (Knight, 2019). High-resolution LiDAR image showing a multi-level forest adjacent to a stream channel is given in Figure 15.

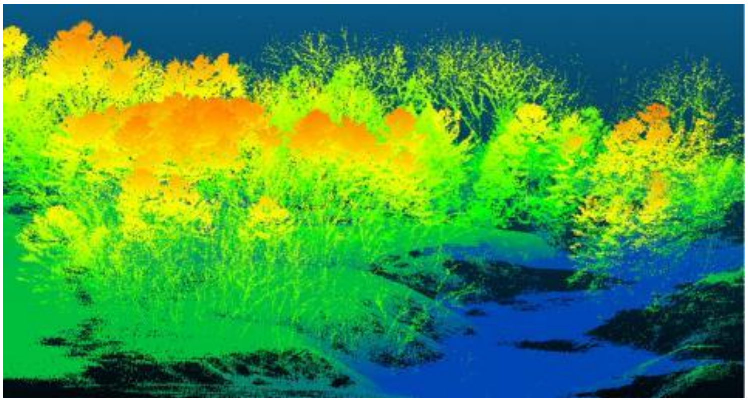

Figure 15. High-resolution LiDAR image showing a multi-level forest adjacent to a stream channel (Anonymous, 2019)

CONCLUSION

As drone and sensor technology continues to advance rapidly, tangible advantages in crop management are already evident. Drones can be employed for basic aerial field observation or to execute systematic mapping missions. Drones can be equipped with various imaging sensors to collect additional information beyond simple RGB imagery. While visible light images result in low interpretation accuracy, the utilization of multispectral images and elevation data contribute to an increase in the overall accuracy rate.

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CHAPTER VI

DEEP LEARNING TECHNIQUES USED IN AGRICULTURE

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INTRODUCTION

Agriculture is one of the most important fields where the essential and basic needs for sustaining human life are met (İtmeç et al., 2022). The primary goal of agricultural production is to ensure economic, sustainable, and productive management in both plant and animal production. During the development period of agricultural production, following mechanization, automation, control, and the rapid development in information technologies, smart machines and production systems controlling these machines have begun to replace traditional production methods today. Information technologies consist of hardware, algorithms, and software developed for the management of processes related to acquiring, processing, storing, transferring, and using information. In agriculture, the evaluation of existing knowledge and experiences, along with machine learning, deep learning, artificial intelligence, modelling, and simulation applications offered by information technologies, has led to the development of real-time and automatic expert systems, autonomous tractors or agricultural machinery, and agricultural robotic applications (Ozguven, 2018).

Artificial intelligence is the capability of a computer, machine, or system to acquire the perception, learning, past experience, and thinking abilities inherent in human intelligence, enabling it to make decisions in the face of predictable or unpredictable new situations and perform the necessary tasks. While machine learning is a subcategory of artificial intelligence, deep learning is a subcategory of machine learning (Kayaalp and Süzen, 2018; Adem et al., 2023). Artificial intelligence, machine learning and deep learning chronology is given in Figure 1 (Kayaalp and Süzen, 2018).

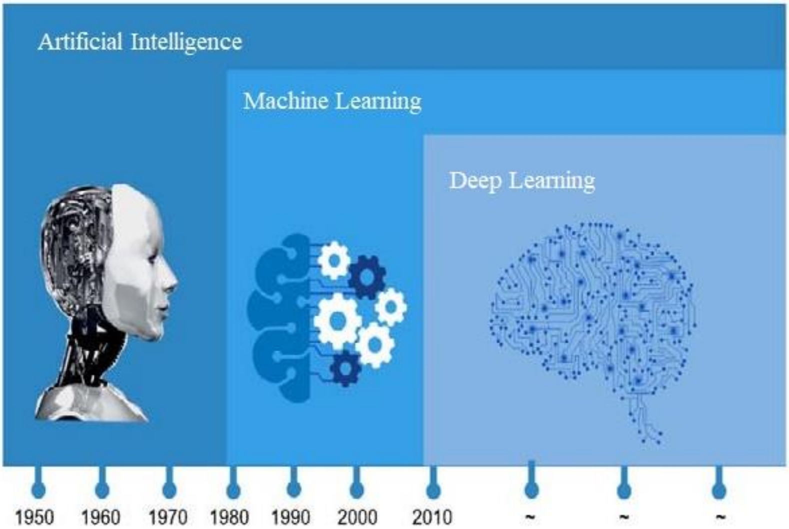

Figure 1. Chronology of Artificial Intelligence, Machine Learning, and Deep Learning (Kayaalp and Süzen, 2018)

The deep learning process repeats until the success rate reaches a certain level. The general steps that data needs to go through in this process are illustrated in Figure 2 (Kayaalp and Süzen, 2018).

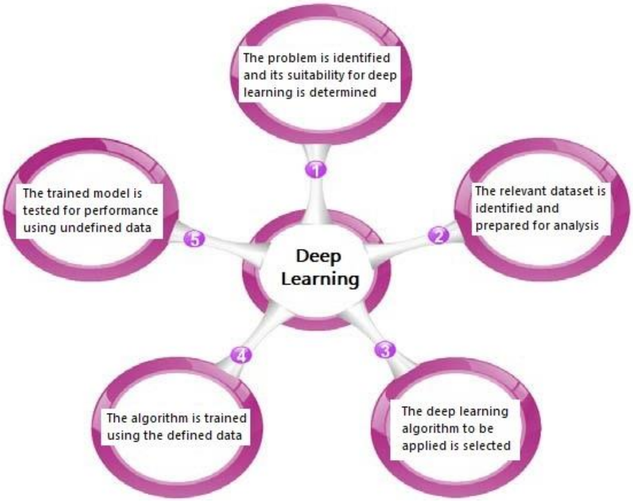

Figure 2. Deep learning processes (Kayaalp and Süzen, 2018)

Deep Learning

Igor Aizenberg coined the term "deep learning" (DL) in the early 2000s, and it gained popularity in 2016 (Goodfelow et al., 2021). By employing artificial neural networks (ANNs) or other comparable ML techniques to translate data into several levels of abstraction, deep learning (DL) enhances the traditional machine learning (ML) model and adds additional nuance and complexity to it (Schmidhuber, 2020) DL is an ANN model that is far more sophisticated. Networks with more than one hidden layer number are referred to as deep learning, whereas ANNs are composed of three layers: input, output, and hidden layers. As illustrated in Figure 3, DL generates an output by self-learning the data fed through hidden layers.

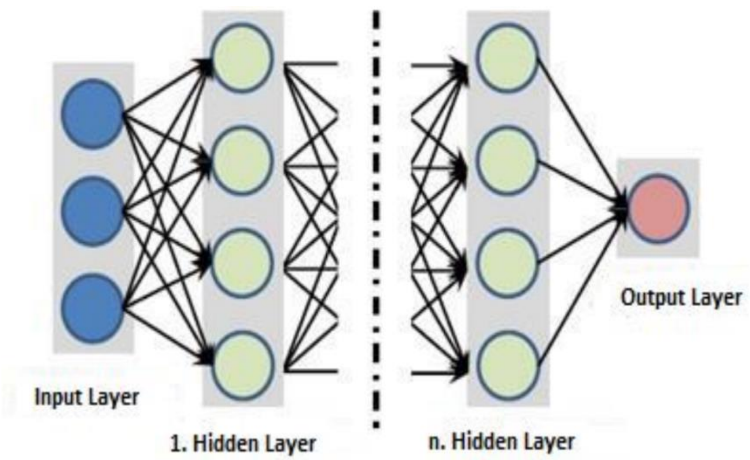

Figure 3. Deep Learning Architecture (Kaya et al., 2019)

According to Seker et al. (2017), it contains algorithms like Deep Belief Network, Restricted Boltzmann Machine, Recurrent Neural Networks, and Convolutional Neural Networks. The benefits of deep learning (DL) are maximum processing speed for unstructured data, high-quality output, and no needless expenses. However, there are certain drawbacks, including the requirement for a significantly higher volume of data and the high cost of both hardware and software. It is utilized in many different fields, such as image processing, facial recognition, driverless cars, natural language processing, and customized shopping lists (Bal and Kayaalp, 2021).

Machine learning includes deep learning. From the early days of machine learning to the present, interest in artificial intelligence has steadily increased. This has led to the creation of deep learning architectures, the most popular artificial intelligence algorithms. In addition to deep learning architectures, many deep learning techniques have been developed to address problems in artificial intelligence. Over the past few years, deep learning has proven to be a viable solution for a variety of problems in a number of application domains. Figure 4 summarizes a plethora of potential real-world applications for deep learning. In conclusion, there is still work to be done, but deep learning modeling offers a great deal of potential for usage in practical applications in the future.

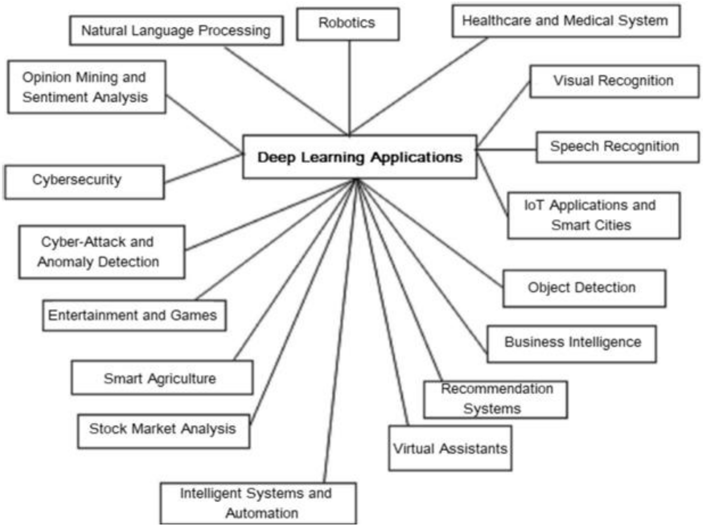

Figure 4. Several potential real-world application areas of deep learning (Alzubaidi et al., 2021)

Advances in computer vision offer an opportunity to expand and enhance precision plant protection practices and to expand such practices in precision agriculture (Sladojevic et al., 2016). It is possible to identify diseased areas and classify disease severity by shape and color characteristics using direct image processing methods in diseased leaf images or by using machine learning methods such as K-means clustering, ANN, SVM, SR, and CNN in addition to image processing methods. The use of deep learning for disease and pests detection in plants has been extensively explored in recent years (Ozguven and

Adem, 2019; Ozguven, 2020). Figure 5 enumerates the benefits of DL application in agriculture. The demand for agricultural products has increased along with the current population growth (Thai-Nghe et al., 2022). By implementing DL and other automation components, production outcomes could be considerably improved, ripening chances could be decreased, production costs could be decreased, and income might rise as a result of greater production. Additionally, it would allow for the prediction of climatic changes, such as the arrival of a cyclone, downpour, etc., allowing farmers to plan ahead and get ready before a disaster strikes.

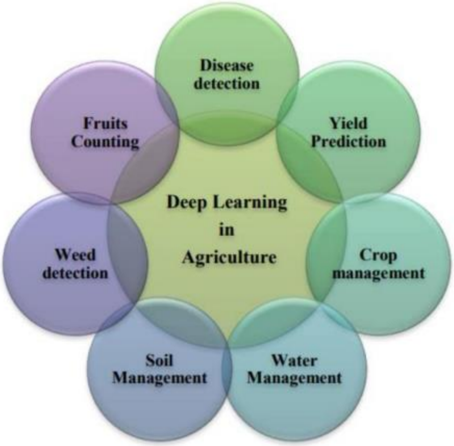

Figure 5. Deep learning applications in agriculture (Thai-Nghe et al., 2022)

DEEP LEARNING APPLICATIONS IN AGRICULTURE

Counting of Fruit

For growers, counting fruit is a crucial duty since it allows them to estimate the production, which can be useful in yard management. According to Chen et al., agricultural production can be maximized and the harvest process can be efficiently managed by employing automated fruit detection and algorithms for fruit counting (Chen et al., 2017). In order to enhance manual fruit counting, Rahnemoonfar et al., suggested automated yield estimation utilizing robotic agricultural techniques (Rahnemoonfar et al., 2017). As a deep simulated learning method, the authors used Inception-ResNet to attain a high accuracy ratio at a reduced computing cost. The method is significant because it can train neural networks without requiring hundreds of photos. Alternatively, a 91% accuracy rate can be attained by training the network with artificial images to verify the legitimacy of photos. Farmers may find it easier to precisely and efficiently count fruit with the use of this innovative DL approach. In a similar vein, Apolo-Apolo et al., trained a Fast R-CNN DL model to identify, tally, and forecast the ideal citrus fruit size (Apolo-Apolo et al., 2020). As seen in Figure 6, the authors also computed the quantity of fruit on each tree using the long short-term memory detection approach. For this reason, DL techniques like DL simulation, automated yield identification, and Fast R-CNN can be useful for counting fruit.

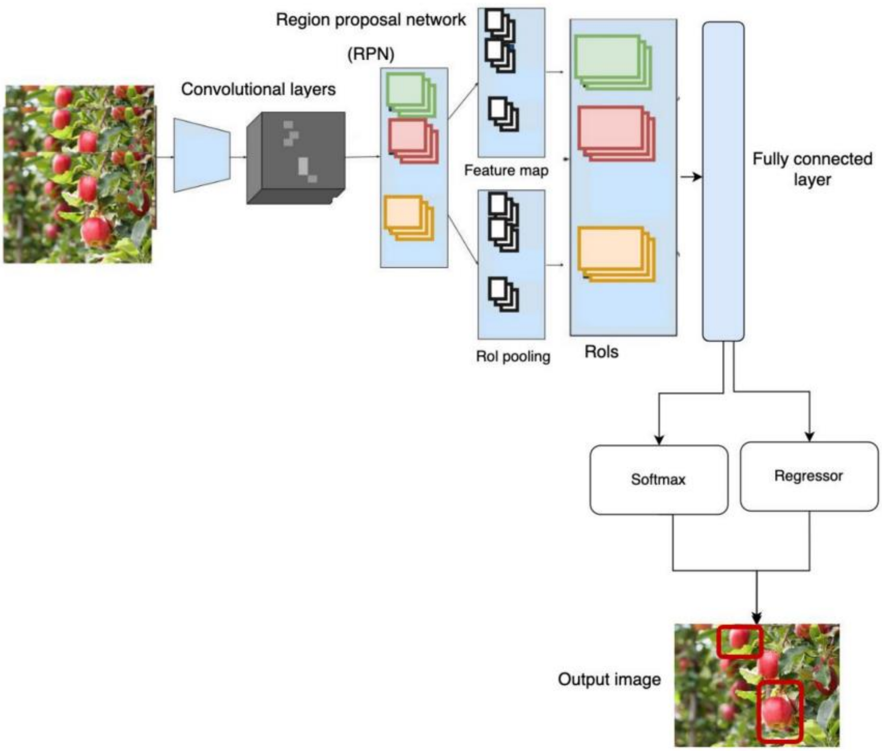

Figure 5. Flowchart for Faster R-CNN (Apolo-Apolo et al., 2020)

Management of Water

Water is a vital natural resource for agriculture, and its continuous and sustainable development depends on its recycling. Water is necessary for farm production, but water pollution is exacerbated by chemicals from industry and wastewater from regular use, according to Chen et al. As a result, DL techniques are required in the agriculture sector to safeguard against water contamination. Mohan et al. posited that agriculture is the backbone of the economy in India and requires water as a significant resource. Traditional irrigation methods waste water due to excessive water use and unplanned water management. As a result, the authors offered an integrative strategy that makes use of DL techniques to enhance India's agricultural irrigation system (Figure 6). The system is made up of sensors that measure the humidity of the soil and forecast when the soil will require irrigation (Mohan and Patil, 2018). Water is a vital resource, and evapotranspiration measurement is highly advantageous. Evapotranspiration evaluation makes use of DL approaches to forecast future water requirements and offer hints that may be useful for managing irrigation in real time. Thus, farmers may more accurately regulate their irrigation systems with the aid of DL approaches.

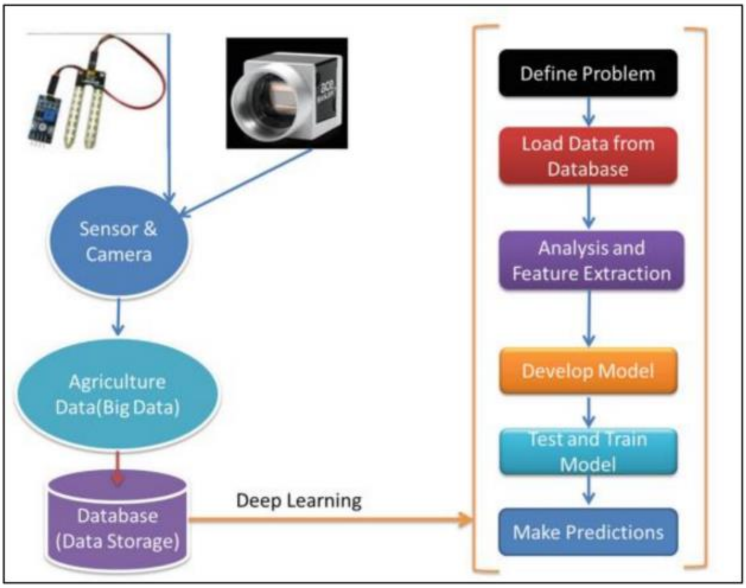

Figure 6. Deep learning approach for water management (Garg et al., 2019)

Crop Management

DL frameworks are becoming more and more important in the agricultural domain of crop management. Crop sowing can benefit from DL technology (Yang and Sun, 2019) The first stage of agricultural production is planting, which must be effectively managed to maximize crop yield. The authors talked about the different DL crop planting techniques, such as CNN, which is used to identify localized features of roots and shoots, Fast R-CNN, which counts and measures the stalks of sorghum plants, ViSeed, which is used to produce soybeans, and VGG-16, which is used to categorize crops and weeds. Many kinds of deep learning networks can be applied to the prediction of crops. ANNs are one of these various sorts; they may be used to estimate the production of wheat, barley, sugarcane, sunflower, and potatoes by using the regression approach, crop species, pictures, and meteorological and soil data. Two-layered DNN LSTM is one of the other DL techniques covered in (Dharani et al., 2021). It has been used to estimate crop yield for tomato, soybean, and maize utilizing the regression method, a vegetative index, environmental factors, and soil. Furthermore, Zheng et al. claimed that accurate crop management depends heavily on intelligence. The CropDeep technique, which recognizes and categorizes various crop classes, was presented by the authors (Zheng et al., 2019). Using cameras and models, CropDeep offers crop management services. It categorizes crops, offers analysis that aids in decision-making, and takes into account real-world difficulties like weather uncertainty (Figure 7).

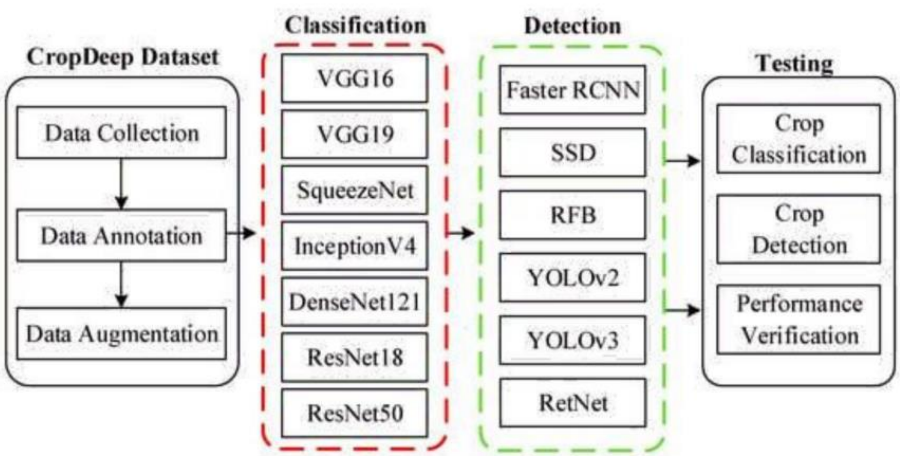

Figure 7. CropDeep deep-learning detection and classification models (Zheng et al., 2019)

Soil Management

The activities, procedures, and treatments that preserve soil and boost crop yield are together referred to as soil management. According to Cai et al. (2019), DL methods can aid in controlling soil moisture. The authors state that it is challenging to create a mathematical model for soil moisture; therefore, the precision, forecasts, and applicability of current models could be enhanced. By fitting the DL regression model with extensive datasets, the authors enhanced its performance and enabled the accurate determination of soil moisture (Cai et al., 2019). According to Yashwanth et al., agriculture has been a vital part of human existence since prehistoric times. A vital component of crop productivity and effective agriculture is soil yield. Thus, the authors talked about how integrating the Keras API into Python can aid in keeping soil moist and shielding it from the harmful effects of herbicides (Yashwanth et al., 2020). Furthermore, the Richard equation can be used to estimate the exact moisture content of soil using a discrete time first-order agriculture simulator (Tseng et al., 2018). The authors clarified that aerial photos with a specific soil moisture information dataset can be obtained with the use of an agriculture simulator. Using a CNN could cut water use by 52%, according to an analysis of the dataset that was conducted using seven different methods, including SVM, NN, and constant prediction baseline (Tseng et al., 2018). The authors' findings thus shown how DL methods can support soil moisture management.

Weed Detection

Unwanted plants like weeds can lower crop yields. Weed detection is aided by DL approaches. A plant is considered a "weed" if it grows in an unsuitable environment (Yashwant et al., 2020) They compete with plants for nutrients, sunshine, and water from the soil, which has a negative impact on agricultural yield. DL methods, such as first-order agriculture simulation with Richard's equation, can be used to detect weeds. By using less weedicides, this method protects the soil from toxicity and guarantees that the plants produce enough yields for acceptable conditions. Furthermore, Westwood et al., expressed worry that weeds have become resistant to herbicides as a result of herbicide production and use. Thus, improving the accuracy of weed detection methods is crucial to raising crop yields. Scholars have deliberated on the breakthrough in computing technology and its potential to enhance our comprehension of the biology and ecology of weeds. The most useful method is DL because it makes weeds easier to identify and eradicate by classifying them into agricultural groups. Similar findings were made by Mishra and Gautam, who discovered that DL methods like CNNs and SVMs for classification can ease the workload on farmers. Farmers can find weeds with the aid of these techniques (Mishra and Gautam, 2021). The writers discussed different methods for classifying and identifying weeds. These methods include first taking pictures of weeds with the camera, and then identifying homogeneity between the photographs using a gray level occurrence matrix. As illustrated in Figure 8, the hue saturation value (HSV) color indicates the weeds' mellowness. Therefore, DL approaches are useful for weed detection, relieving farmers of some of their workload and boosting crop productivity.

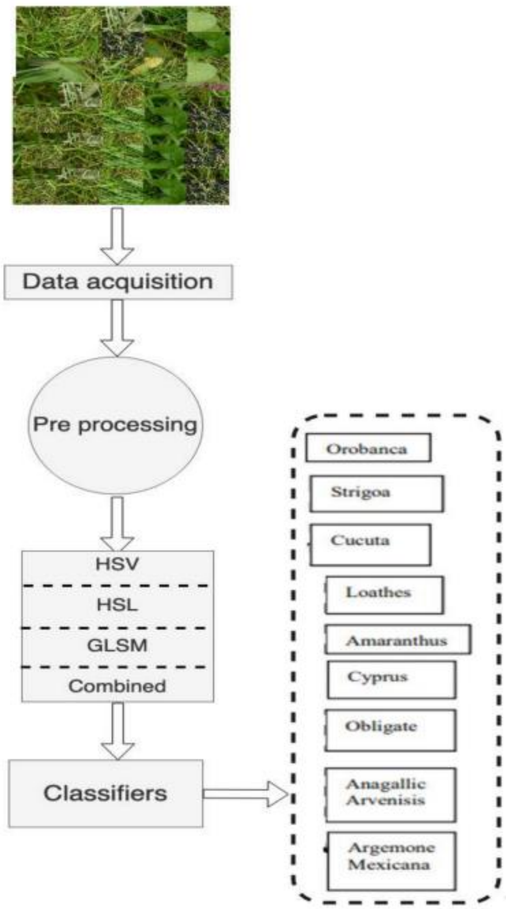

Figure 8. Flowchart for weed detection and classification (Mishra and Gautam, 2021)

Seed Classification

Crop production in the agricultural sector is heavily dependent on seeds. According to Gulzar et al., the production of crops depends heavily on seeds, without which it would be impossible to produce and harvest crops. The precision required in seed identification and classification has put pressure on agricultural expansion due to the higher rate of population growth. In order to improve the effectiveness of seed categorization, the authors suggested using a CNN. Decayed learning points were one of the approaches employed in this strategy (Gulzar et al., 2020).

Classification of Plant Diseases

Plants that are infected with bacteria, fungi, or both may yield fewer crops. In the event that farmers do not receive a timely diagnosis, the disease may result in substantial financial losses. The expensive pathogen-killing insecticides that are used to eradicate pests and return crop functionality are employed. Overuse of pesticides harms the ecosystem and can interfere with soil and water cycles (Sharma et al., 2020). Plant infections must be detected early on because they impede growth. A variety of plant diseases have been identified and categorized using DL models. To increase detection accuracy, a number of DL architectures have been put forth (Saleem et al., 2019). Several CNN and DL topologies, including Wide ResNet, DenseNet, MobileNet, and ResNet, have been thoroughly studied by researchers. The outcome shown that the suggested method outperformed earlier approaches in the literature in terms of accuracy and memory. Another CNN-based technique for recognizing, categorizing, and detecting plant diseases was put out. There was a range of 91 to 98% accuracy in identifying 13 distinct plant diseases. In addition, the suggested model could differentiate between the backgrounds of healthy and unhealthy leaves (Sladojevic et al., 2016). Arivazhagan et al., suggested a model based on an SVM classifier using 500 distinct leaf pictures. With an accuracy of 94%, the suggested model could correctly diagnose plant diseases (Arivazhagan et al., 2013).

Yield Prediction

Yield projections for every crop require considerable attention to detail and concentration. Crop yield prediction is the main focus of DL algorithms and agricultural machine learning. They advise the farmer when the crop will be ready for cultivation as well as whether it is ready now (Kavitha, 2021). Crop production prediction has been the subject of extensive research. Using input data on weather, soil, and management, implemented a neural network with one hidden layer for the prediction of maize production. Stepwise multiple linear regression, projection pursuit regression, and neural networks were used to estimate agricultural yield in the same scenario. They consequently discovered that the neural network approach performed better than both regression techniques (Khaki and Wang, 2019).

Disease Detection

Crop disease is one of the biggest threats to farmers in the agricultural sector. Crop disease identification has become one of the simplest procedures as a result of advancements in AI and DL and their application in the agricultural sectors. Early crop disease identification was a laborious and time-consuming operation that had to be done by hand prior to the use of sophisticated technologies in agriculture (Ale et al., 2019). Plant diseases have a major negative impact on a nation's economy in addition to stunting plant growth and population expansion. Therefore, in order to manage disease, ensure food safety, and forecast return losses, it is imperative to implement automated and precise methods for the prediction and detection of plant disease severity. To address this crop disease problem, some effort has been done. A CNN-based approach for detecting crop diseases was proposed by Zhu et al. When the system was compared to the conventional crop disease detection system, its accuracy rate was 89%. Therefore, CNN systems are dependable when it comes to image processing because they are frequently utilized in agricultural research. Plant and crop classification, which is crucial for yield prediction, robotic harvesting, pest control, and disaster monitoring, can be used to classify the majority of DL applications in agriculture. Models for identifying plant and crop diseases primarily rely on pattern recognition and pictures of leaves (Zhu et al., 2018). As a result, DL and AI models could identify damaged plants automatically and notify farmers so they can take appropriate action. An illustration of how DL and AI can identify plant diseases is provided in Figure 9.

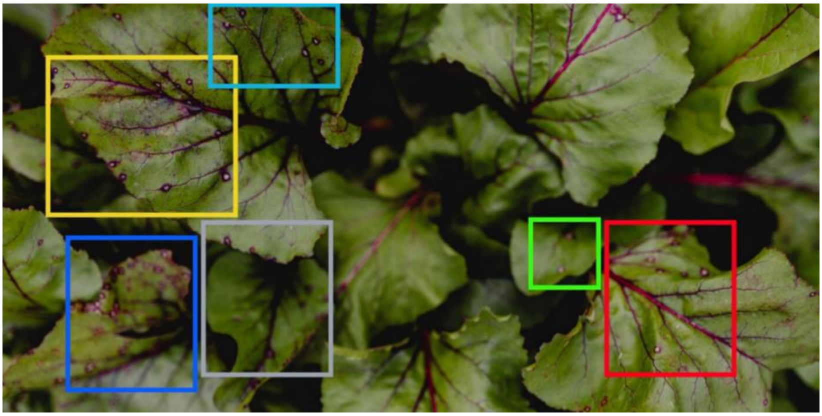

Figure 9. Plant disease detection (Albahar, 2023)

CONCLUSION

The research' conclusions demonstrate how DL mechanisms have benefited farmers in various aspects of agricultural output. These include harvesting, weed identification, seed categorization, yield prediction, disease detection, crop management, water management, and fruit counting. The agriculture sector has profited from DL in a number of ways. There are several obstacles facing agriculture because there are fewer personnel in the industry and higher demand. Nonetheless, the application of smart farming can improve agricultural production efficiency and help solve concerns like productivity, environmental impact, food security, and sustainability (Santos et al., 2019). As is commonly known, agriculture is crucial to the global economy because it provides food security for local communities and is the primary means of exporting goods for most companies. Using the most recent prediction analyses and tools, the agriculture industry has expanded and developed thanks to the application of deep learning techniques.

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CHAPTER VII

YIELD MONITORING INSTRUMENTATION APPLIED TO THE COMBINE HARVESTERS

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INTRODUCTION

Precision Agriculture (PA) is a new agricultural technology that optimizes the profit by improving agricultural efficiency while protecting the environment with the reduction in the amount of chemicals applied to the agricultural fields (Bayat et al., 2023). It can be defined as the management of inputs based on the needs of the small sites (generally 4-10 da) of the fields with the use of variable rate application instead of conventional constant rate application. Two important benefits of the precision farming are the possible reduction in the cost of production and more importantly, the prevention of unnecessary use of chemicals which impacts the nature in a bad way (Keskin et al., 1999a). It is known that the properties of a field are variable in its soil, topography and other factors (like soil texture, topography, nutrient levels, pH level, weeds, pests, etc.) which affect the development of plants and consequently the yield. Once the variability in a field is determined in a way, then the variable-rate application of the agricultural inputs can be applied leading a reduction in chemical usage and an optimization in yield. The precision farming technologies can be classified into three main groups as Data Collection, Data Processing/Decision Making and Variable-Rate Application technologies. The first group technologies provide the farmer the essential spatial data to conduct the site-specific management. Second group includes the Geographic Information Systems that are used for data storage, processing and analysis and decision making purposes. The last group that includes Variable Rate Application Technology is the actual application of the precision agriculture. After the precision agriculture data is collected and interpreted using the GIS, the decision making process is conducted to determine the appropriate treatment to the field. The treatment may require variable-rate application (VRA) of the agricultural inputs like seed, fertilizer, pesticides and tillage. VRA is only one management type to address the spatial variability. Other management decisions may be conventional constant rate application or seizing the farming a field or a small part of a field due to the poor production and high input costs.

Especially in Europe and the USA, it is a common practice to make partial applications as a transition period before the full implementation of precision agricultural technology elements in agriculture. Yield mapping technology is one of the technologies used in precision agriculture that has found the most application today. Yield mapping technology is carried out by applying two different methods. In the first method; There is the use of yield monitoring systems and mapping software or GIS (Say et al., 1999). The second method is; It requires the use of aerial photography and GIS.

Apart from these two methods, yield mapping can also be done by harvesting from different points of the agricultural land, sampling small and equal areas, with the use of manpower. The location (latitude and longitude) of each sampled point can be determined with a handheld positioning device (GPS). This method is quite tiring, especially for large agricultural lands, and is not economical in countries where labor costs are high. Therefore, it cannot be used for commercial purposes, but can be used for scientific purposes for the calibration or accuracy control of other yield mapping methods.

Yield Monitoring System

The method, which is based on the use of a yield monitoring system, requires the use of yield monitoring systems consisting of different sensors (Figure 1) placed on the harvesting machines.

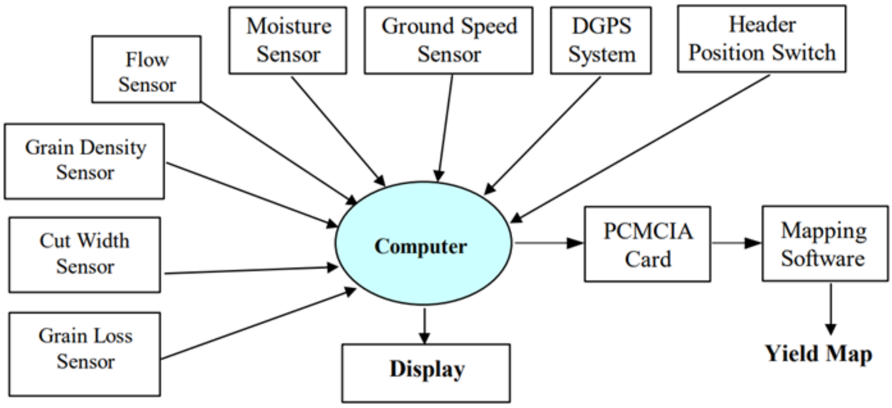


Figure 1. Schematic of the components of a yield monitoring system for a combine (Keskin et. al., 1999a)

The computer in the system calculates the instantaneous efficiency using the signals coming from the sensors. It records the calculated yield data, together with the location data (latitude and longitude) coming from the positioning system in the system, on the PCMCIA card (a recording medium similar to a floppy disk) at certain intervals (usually 1-2 seconds) in the form of an ASCII file (Keskin et al., 1999b).

Figure 2 shows the placement and general structure of the screen part of the system in the cabin of combine harvester.

Figure 2. A yield indicator placed inside the harvester cabin (Keskin et al., 2000)

The system monitors during the harvest and contains basic information about the amount of yield harvested on a dry and wet basis, the amount of harvest per unit area, yield moisture content values, the name of the harvested area, its coordinates and GPS status. The processes applied in the yield mapping made with the yield monitoring system (together with the processes applied in the second method, the principles of which will be explained) are given in Figure 3.

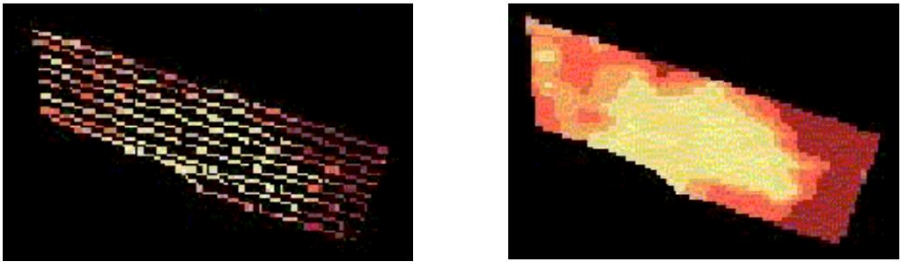
After the yield and location data in ASCII file format are transferred from the PCMCIA card to a desktop computer, the process of obtaining the yield map begins. Optionally, a GIS or mapping software is used to convert yield data with location information into a yield combination. In the use of GIS, data stored as ASCII files are first converted into a point map (point coverage, point layer) showing each data acquisition point and the yield value of that point. This point yield map is converted into a classified yield map by applying the classification process after using a suitable interpolation method.

Figure 3-a shows an example point yield map and Figure 3-b shows an example classified yield map obtained as a result of the interpolation process applied to the point yield map.

Mapping software can also be used instead of GIS to obtain the yield map. Mapping software has similar features to GIS, they are simpler, cheaper and have special features for mapping purposes. Therefore, this method is more practical than the first one. According to the features of the software, the data in ASCII file format is converted into a classified yield map by applying the necessary process.

This type of software can generally be obtained from the company from which the yield monitoring systems are purchased. Generally, the yield map is classified using a number of yield classes: low, medium and high.

A classified yield map is shown as an example in Figure 3-b, and in this yield map, more efficiency was obtained from the dark colored regions. The efficiency value is higher in dark colored regions, and the efficiency value is lower in light colored regions. When the sample figure is examined, it is seen that the yield values are higher in the eastern part of the field and lower in the middle parts.



(a) (b)

Figure 3. An example point yield map (a) and an example classified yield map (b) (Keskin et al., 2000)

Yield Monitoring with Aerial Photography

Remote sensing technology can be defined as the technology of detecting radiation reflected from the earth and objects on the earth and obtaining information about the object or surface sending the radiation by processing these radiations appropriately for the desired purpose. In this method, data collection is carried out with detection systems placed on satellites, aircraft (planes, balloons, etc.), ground vehicles (tractors, etc.) and stationary platforms.

In the yield mapping method based on the principle of aerial photography, the yield value is not measured directly, but is indirectly estimated with the help of one of the green cover coefficients (vegetation index) obtained after processing the photographs with GIS (usually NDVI).

The procedures applied in this method are shown in Figure 4. The first process applied is the data collection process, which consists of obtaining photographs of the agricultural land in two separate bands (red and short infrared) with a photography system placed on a small aircraft. Photography system placed on the aircraft; It consists of two separate cameras, one taking photographs in color and the other in the short infrared (NIR) band. It is appropriate to take the photographing under suitable weather conditions and at noon (in order to eliminate the negative effects that may occur due to shadowing). Before the photography process, signs (at least 4) that can be easily seen in the photographs are placed in the corners of the agricultural land, and the latitude and longitude coordinates of these points are determined on the field with a location determination system. During the recording process, these points are determined on the photograph, the coordinates of the points are entered and the photographs are recorded. In this way, each point on the photo has real coordinate values according to the latitude and longitude system. Following this process, after the photographs are converted into cell (raster) format files, the green cover coefficient (NDVI) to be used in estimating the yield is calculated with the help of an equation. After NDVI values are obtained, the yield map is obtained from the NDVI map by using the appropriate calibration equation (the equation stating the relationship between yield and NDVI). After the yield map is obtained, the classified yield map is obtained by applying the classification process. The accuracy level of the method with the yield monitoring system is generally better than the other method, and the accuracy of the method depends on the sensitivity of the yield monitoring system used. For example, highly accurate yield monitoring systems for combine harvesters have become widespread in the last decade. For this reason, the accuracy level in yield mapping for grains is quite high and its use is widespread.

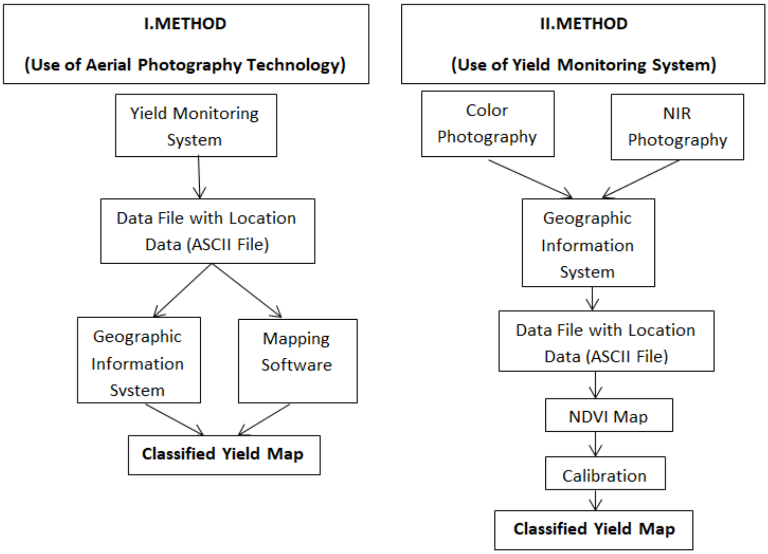


Figure 4. Operations applied in both yield mapping methods (Keskin et al., 2000)

Yield monitoring systems for cotton harvesters are in the experimental phase and their accuracy depends on eliminating some problems related to their use (Wolak et al., 1999), and therefore the accuracy of the yield maps obtained may not be sufficient. On the other hand, yield monitoring systems for some other agricultural products are not commercially available and are in the experimental stage, so it is not possible to apply the yield monitoring system method for such products.

The use of the yield monitoring method is quite common (especially for grain products). The remote sensing method is still in the experimental phase and its use is limited.

Yield Monitoring Techniques

There are three different approaches to calculating crop yield (Morgan and Ess, 1997); The first is the basic and antiquated collect-and-weigh method. After harvest and transportation, harvested crops are weighed using scales at a grain receiving facility or on wagons equipped with scales. The batchtype yield monitoring approach comes in second. Particularly for grains, this kind of yield monitor has been provided. When grain is being discharged from the grain tank, the system weighs it as it is being loaded into a wagon. The final one is yield monitoring while on the go, which measures and logs the area and yield continually while the crop is harvested. To estimate the yield, the area collected must be calculated for both batch-type and collect-and-weigh procedures. For site-specific management, the yield figures obtained using these techniques are insufficiently site-specific. They do not, however, necessitate a separate weighing operation or much time. The yield monitoring method that works best for the PA is on-the-go yield monitoring since it records yield, area, and data point positions all at once.

Yield Monitoring Instrumentation for Combines

It is feasible to ascertain the yield variability in the fields by utilizing the cutting-edge technologies of today. The early 1990s saw the availability of the required instrumentation, particularly for grain harvesters. This paper discusses on-the-go yield monitoring equipment that must be installed on a combine harvester in order to collect georeferenced yield map data. Figure 1 shows the design of the system's components, and Figure 5 shows where these sensors or parts are located on an axial-flow combine harvester.

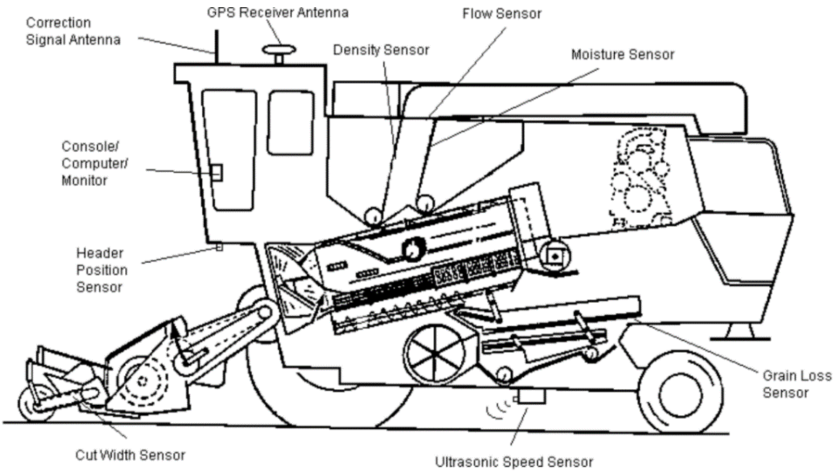


Figure 5. An axial-flow combine harvester equipped with a yield monitoring system (Keskin et al., 1999a)

A combine harvester's yield monitoring system, as shown in figure 5, consists of a computer/display console, flow sensor, moisture sensor, ground speed sensor, header position switch, DGPS unit, cutting width sensor, grain loss sensor, and grain density sensor (if the flow sensor is volumetric in type). Each sensor is explained in detail and discussed.

1) Flow sensor: The yield monitoring system's most crucial component. Flow sensors assess crop flow on harvesters in a variety of ways in order to calculate yield. Figure 6 illustrates these many techniques.

a) Impact force sensor, also known as the Greenstar sensor: specifically utilized for grains. An impact plate can be used to detect grain flow. When the grain hits the spring-loaded plate, it applies force to the plate. A load cell is used to quantify the force, which is proportional to the grain flow. The sensor transforms the load into an electrical signal. A potentiometer can also be used to measure the displacement of the plate. The impact plate moves when grain hits the spring-loaded plate. According to Johnson (1996) (Figure 6), the displacement is proportionate to the amount of grain contacting the plate.

b) Weight-based sensor: This kind of flow sensor weights the crop as it passes through the conveying system of the harvester. The conveying system weight change is essentially the variable that is being monitored. For instance, as grain travels through the clean grain auger of a combine harvester, it is weighed. A load cell senses the change in the auger's weight. The amount of grain going through the auger determines how much changes. The connection is used by the radiometric sensor to calculate the crop weight (Morgan and Ess, 1997; Figure 6).

c) Radiometric sensors, also known as flow control sensors, are made up of a detector and an isotropic (Americium 241) or radioactive source. Radiation from the source is directed at a detector. The amount of radiation that the detector detects will be lessened by any impediment that stands between it and the source. The amount of grain between the source and the detector determines how much of an intensity drop occurs (Morgan and Ess, 1997; Figure 6).

d) A volumetric approach using a photometric sensor (Ceres sensor). A light source and a photo sensor make up the system. The photo sensor picks up light that is sent by the light source when it emits light. Crop volume flow rates are estimated using measurements of the photosensor's output signal's dark and light periods. Since this method indicates the crop's volume, measuring the bulk density of the crop is also required in order to calculate yield (Morgan and Ess, 1997; Figure 6).

e) The paddle-type sensor, also known as the Claydon sensor, is another volumetric approach that makes use of photometry, as shown in Figure 6. The sensor is made up of a paddle, a light source, a grain level detector (a type of light detector) and an electromechanical driving mechanism for the paddle. Grain is discharged until the grain level drops below the light detector level when the grain level rises and blocks the light beam from reaching the light detector. This is accomplished by an electromechanical clutch that engages a hydraulic motor, which rotates the paddle wheel. Since each paddle division's volume is known, a reed switch decides how many rotations there are, which leads to the amount of grain. The crop's volume is approximated based on the number of rotations and the volume the paddle division (Durrence, 1997).

f) Force plate sensor: Using a curved plate or tube, this sensor changes the grain's direction. It is believed that the velocity change is constant. The change in mass flow and the resulting force change together. Increased drain exerts more stress on the plate. The force can be measured using a load cell, and its relationship to the grain mass can then be established (Durrence, 1997; Figure 6).

2) Moisture sensor: The weight and volume measurements of the crop are impacted by its moisture content. Both the weight and the volume will increase with a higher moisture content. In order to convert all yield data to a standard moisture value, moisture content must be recorded at the time of harvest. The moisture content of the crop is often measured using a capacitance-type sensor. Two metal plates with a dielectric substance separating them make up a capacitor. The crop that passes between the two metal plates is measured by the sensor for its dielectric characteristics. The moisture content increases with the dielectric constant. Figure 7 shows a grain moisture sensor of the capacitative kind (Johnson, 1996).

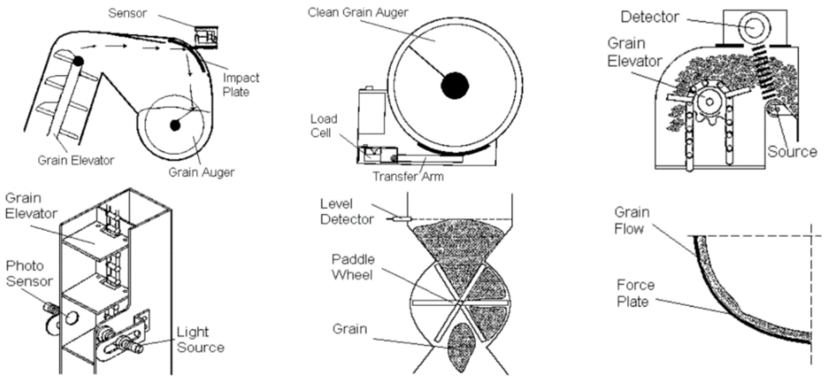


Figure 6. Flow sensors: impact force sensor (top-left), weight-based sensor (top-middle), radiometric sensor (top-right), photometric sensor (bottom-left), paddle-type sensor (bottom-middle), force plate sensor (bottom-right) (Keskin et al., 1999a)

3) Cutting width sensor: Although the combine harvester's potential cutting width is known, it is always less than that amount during actual harvesting conditions. It is necessary to know the current real cut width in order to monitor yield accurately. The cutting width sensor calculates the separation on both sides of the cutting table between the crop side and the cutting table side. Less than the measured distance should be the width of the cut. Figure 7 shows an ultrasonic type cut width sensor (Morgan and Ess, 1997).

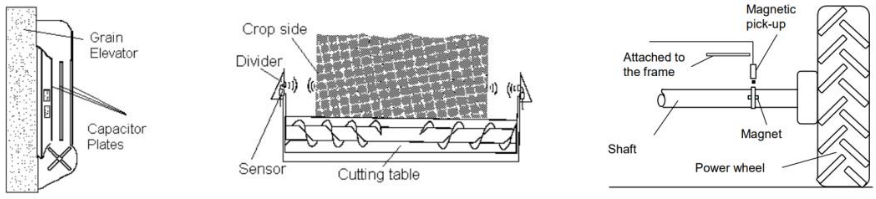


Figure 7. A capacitative grain moisture sensor (left), an ultrasonic cutting width sensor (middle) and a magnetic speed sensor (right) (Keskin et al., 1999a)

4) DGPS unit: When the combine harvester is operating in the field, the DGPS (Differential Global Positioning System) unit detects its exact location and provides this information in a manner that is compatible with computers. The DGPS unit is made up of two parts. The first is the GPS receiver, which uses signals from satellites to calculate the machine's current position. The second one is the receiver for differential correction signals, which gets the signal from a base station. Insufficient accuracy would result from using position data without differential correction. Using the differential correction receiver is intended to improve position determination accuracy.

5) Ground speed sensor: One of the factors that need to be understood in order to calculate yield is the harvester's ground speed. The harvesters' ground speed can be determined in a few different ways.

a) Magnetic shaft speed sensor: Wheel speed and the combine's transmission output shaft speed are intimately correlated. To measure, a magnetic sensor is employed. A magnetic pick-up is positioned at a distance of approximately 0.5 cm from the magnet, and a magnet is fastened to the shaft. The magnet generates a peak signal per revolution of the shaft. Nonetheless, the combine driving wheels' tendency to slip could cause mistakes in the sensors. The harvester's tires experience an increase in weight when its tank fills, which deflects the tires and shortens the rolling radius of the drive wheels. This is another source of inaccuracy. The precision of the ground speed measurement is impacted by these issues (Figure 7).

b) Ultrasonic and radar sensors: According to Morgan and Ess (1997), these kinds of sensors are more accurate than magnetic shaft speed sensors. Both varieties employ guns that aim the signal downward. Whereas ultrasonic devices produce high frequency sound waves, radar systems produce microwave signals. The ground reflects the signals back to the sensor. The signal that returns to the speed sensor will have a shift in frequency. The frequency shift is used to measure speed and is correlated with ground speed. As seen in Figure 8, both systems are often positioned on the harvester's frame near to the ground.

c) DGPS-based speed measurement: With an instantaneous change in location relative to the direction of travel, a DGPS receiver can determine the harvester's speed. The location precision of the receiver determines the speed accuracy. A yield monitor uses DGPS data sentences to extract speed information, which it then interprets to determine ground speed information. Given that the system already contains a DGPS unit for determining position, this form of speed measurement is the most cost-effective.

6) Computer/console/monitor: The computer console, which connects the signal lines to the computer, receives signals from every sensor.

The instantaneous yield and moisture are computed by the computer and recorded together with the position data. The operator can easily view the monitor because it is situated in a convenient location within the cab. The operator can enter data into the system, such as field names and calibration data, by using the keypad located on the display. The data that can be shown includes yield, crop moisture content, speed, and so on. There can be some differences between the measured yield and the actual yield because the yield is not measured directly but rather computed utilizing the required variables that are gathered from the sensors. This calls for the requirement for a calibration process. The yield monitor's projected yield value is compared to the load's measured weight using a scale as part of the calibration procedure. The farmer can then use the display keypad to calibrate the yield monitor by entering the actual weights. Subsequently, the computer generates a series of calibration curves designed to reduce the discrepancy between the measured and real yields.

7) Grain loss sensor: The quantity of grain that the harvester releases into the field must also be taken into consideration for precise yield monitoring, and this can be done by adding to the existing yield figure. The quantity of grain that the harvester releases is measured by the grain loss sensor. Beneath the cleaning sieve is an impact table fixed on the sensor. The grains make contact with the dish. Each grain that strikes the plate produces a peak signal, and the amount of grain lost may be calculated by counting the peaks in the signal (Figure 8).

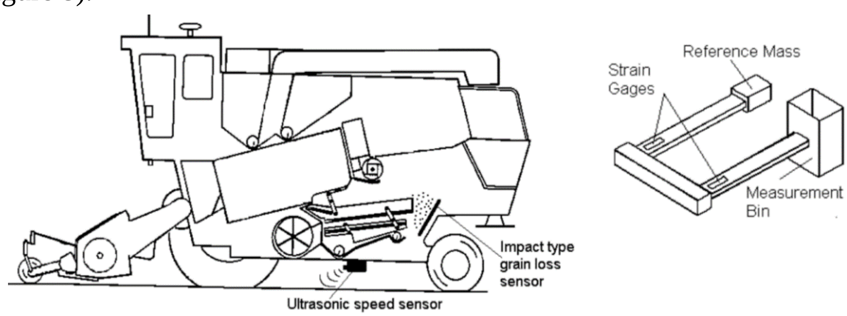


Figure 8. Ultrasonic speed sensor and grain loss sensor (left) and grain density sensor (right) (Keskin et al., 1999a)

8) Grain density sensor: The grain's volumetric flow is measured by volumetric type flow sensors. However, because the yield is expressed in mass units, the volumetric yield needs to be multiplied by the density in order to be transformed into a mass unit. One device that can assess density automatically is depicted in Figure 8 (Reitz and Kutzbach, 1996). Using a strain gage, the mass of the measuring bin is determined, and its volume is known. The vibrations and gradients are taken out of the equation by using a reference mass.

9) Header position (on/off) sensor: This sensor notifies the computer to stop the area and yield computation when there is no crop in the harvesting unit of the harvester when the header is raised. The yield calculation then resumes when the header is lowered. Turnings at row ends and other non-crop areas employ this function.

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CHAPTER VIII

DEVELOPMENT OF SOME RHEOLOGICAL PROPERTIES OF SPRAYED LIQUID IN PESTICIDE APPLICATIONS

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INTRODUCTION

Adjuvant is a broad term that describes any additive added to a spray tank that increases pesticide activity. Examples of adjuvants include surfactants, spreading adhesives, crop oils, antifoams, pH or buffering agents, and compatibility agents. Surfactants are adjuvants that facilitate the emulsifying, dispersing, spreading, wetting or other surface-modifying properties of liquids. Among these additives, surfactants and drift guards stand out in terms of usage (Czarnota and Thoma, 2013; Bayat and Zeren, 1999).

Just like a magnet, each water molecule is bipolar, meaning it carries both a positive and negative charge. The surface molecules of a water drop are held together with a greater force than the core water molecules. Many substances may not dissolve in solutions due to surface tension. Most surfactants have a polar head that prefers water (hydrophilic head) and a non-polar tail that does not (hydrophobic tail). There are four classifications of surfactants based on the charge present in the hydrophilic head. These classifications include nonionic (carrying no charge), anionic (carrying a negative charge), cationic (carrying a positive charge), and amphoteric (carrying both a negative and positive charge) (Kume et al., 2008). In general, surfactants have a chain structure that is mainly attributed to the structure of the hydrophobic tail (Azam et al., 2014). When a surfactant is in aqueous solution, the presence of the hydrophobic part of its molecule causes a distortion in the solvent structure that increases the overall free energy of the system (Myers, 1992). This allows the surfactant molecules to adsorb at the interface with the hydrophobic portion directed away from the water. This reduces interfacial tension (less energy is required to move molecules to the interface). The decrease in surface tension increases as the surfactant concentration increases. The results obtained show that the interfacial rheological properties caused by the surfactant can have a significant effect on the droplet size (Padron and Calabrese, 2023; Hilz and Vermeer, 2013).

According to Burnham et al., (2013); Gbadamosi et al., (2019b), the tail group of a surfactant usually consists of a short polymer chain, a long hydrocarbon chain, a siloxane chain, or a fluorocarbon chain. The head group consists of parts such as sulfates, sulfonates, polyoxyethylene chains, carboxylates, alcohols or quaternary ammonium salts. The presence of these groups determines the amphiphilic nature of the surfactant. When the effects of keeping the spray liquid on the leaves are examined, it is observed that on performance; It has been determined that the surface tension of the spray liquid, the size of the incoming droplets, the viscosity of the spray liquid, the speed of the falling droplets, and the average incidence angle of the spray on the leaf surface are effective (Brunskill, 2023). In addition, there are different additives such as antifoam, buffer or pH regulator, drift control agents (Hock, 2022).

Characteristic features of adjuvants

Various additives are used to increase the effectiveness of pesticide formulations in plant protection. Additives are chemicals that can improve the effect of a pesticide or change its properties. Surfactants are used to improve the biological effectiveness of the sprayed material by regulating the physical characteristics of the application solution. Most plant protection products produced today aim to improve pest management and prevent pesticide drift (Özlüoymak, 2022). Surfactant/counterion chemical structures can form rod-like micelles if their molar ratio, concentration, and temperature are under the right conditions. This network microstructure provides viscoelasticity to the solution flow and is often stated to be responsible for its formation (Ketan, 2009; Li et al., 2008). Hilz and Vermeer (2013) stated that the three adjuvant properties that affect the disintegration of the spray liquid layer are viscosity, surface tension, and the presence of inhomogeneities such as emulsion droplets or solid particles. Chemicals produced as anti-drift properties are mostly organophosphorus, polymer-added or oil-based compounds (İtmeç et al., 2022). Drift guards change the elastic properties of the application mixture, allowing the mixture drops to be larger than the average weight and width and minimizing the number of small drops that can be easily carried by the wind. Drift guards agents are generally polymers such as polyacrylamides and polysaccharides, as well as certain gummy substances. Polymer additives change the flow configurations of multiphase flows in such a way that the stratification of individual phases is improved, thus making separation of phases at the liquid destination much easier (Topuz et al., 2011; Tu and Randal, 2001).

A polymer is a substance with a similar macromolecular structure that binds together by forming a chain of repeating units. Polymers are divided into two types: synthetic polymers and polymers composed of natural materials. The difference between synthetic polymers and natural polymers is their degradability. Synthetic polymers are difficult to degrade and cause environmental problems. However, polymers have become a good benchmark in drift-reducing research using additives of two types. Parameters affecting the performance of polymers can be grouped into polymer parameters and flow parameters. Polymer parameters can be evaluated as polymer molecular weight, charge density, chain flexibility, polymer chemical structure, morphology and concentration. Flow parameters include geometry, roughness, size of transmission line or channel, solvent type and salt content, and pH and temperature (Abubakar et al., 2014). The chemical structure of the polymer affects two main properties that are essential for polymer resistance reduction performance. These are the flexibility (or stiffness) of the polymer and its mechanical resistance to hydrodynamic forces. Flexible polymer chains performed better than rigid ones (Jaafar et al., 2009; Paschkewitz et al., 2005). Polyelectrolytes have been found to have a larger volume than non-ionic polymers due to the presence of electrostatic repulsion between charged segments in the polymer chain (Knudson et al., 1992).

Reducing interfacial tension

Interfacial tension is generally defined as the attractive force between molecules at the interface of two fluids (Cong et al., 2020; Kalantari Meybodi et al., 2015). Interfacial tension between water and other molecules causes an increase in capillary force, which plays an important role in retaining other molecules in the medium. Therefore, surfactant injection is used as an option to reduce interfacial tension (Hosseininoosheri et al., 2016). The presence of surfactant in water reduces the surface tension because the surfactant molecules replace some of the water molecules on the water surface. The attractive forces between water and surfactant molecules are less than the attractive forces between water molecules themselves. Then, the contractile force responsible for surface tension decreases (Hu et al., 2016; Mohapatra et al., 2014). Wettability is the ability (or tendency) of a fluid to adhere or spread on a solid surface in the presence of other immiscible fluids (Jing et al., 2019; Yang and Zhou, 2020). Essentially, this type of adhesion occurs due to various forces, including van der Waals forces, structural forces, and electrostatic forces, resulting in stable distribution of fluids in the medium (Wang et al., 2018).

Critical micelle concentration (CMC)

Micelle is a term that refers to the aggregate form of surfactant molecules dispersed in a liquid colloid (Bhosle et al., 2020; Naseri et al., 2018). The critical micelle concentration (CMC) is the amount of concentration that minimizes surface tension. The surface tension remains nearly constant as any new surfactant added above the CMC will either join the micelles or form new ones. In CMC, various physicochemical properties of the solution (e.g., thermal and electrical conductivities, viscosity, and surface tension) change suddenly (Sabahi et al., 2017). The CMC of a particular surfactant depends on the molecular structure of the surfactant (e.g. hydrophobic chain length) (Glennie et al., 2006), pressure conditions (Thiruvengadam et al., 2020), solution salinity (Bratovcic and Nazdrajic, 2020), has shown that it is affected by ionic composition, pH, temperature (Harutyunyan and Harutyunyan, 2019) and other parameters (Puntervold et al., 2018; Zhang et al., 2019a; Zhang et al., 2019a).

Synergistic effect of surfactants and polymers

Anionic, Nonionic and Amphoteric additives are mostly used as surfactants in plant protection (Toraman and Bayat 2015). According to the results of some studies, it has been reported that there is a good synergistic effect between surfactants and polymers. Tighter adsorption was produced at the liquid interface due to the electrostatic effect between the surfactant molecule and polymer-structured agents, resulting in a lower surface tension than the surfactant solution alone (An et al., 2022). Achieving ultra-low surface tension requires the interaction between the elements that make up the liquid to reach an equilibrium, and reducing the surface tension depends on the temperature, the chemistry of the content, etc. is affected (Cui et al., 2012). Combining two surfactants is also common, such as the combination of anionic and nonionic surfactants and the combination of anionic and amphoteric surfactants (Cui and Feng, 2021).

Application effects analysis of spraying additives

In practical terms, variations in viscosity did not cause a significant change in the retention percentage of larger spray droplets in the experiments. In smaller droplets, there is some evidence that retention increases with increasing viscosity. According to Padron and Calabrese, (2023), when a surfactant is adsorbed at a deforming interface, it affects both the static interfacial properties and its dynamic response to equilibrium-induced perturbations. The resulting rheological behavior of the interface affects the drop deformation and fragmentation mechanisms and the final or equilibrium drop size distribution. Therefore, a fundamental understanding of interfacial transport phenomena and their effects on surface elasticity and viscosity, as well as a framework for measuring their effects on the final drop size, is required. When a surfactant is in aqueous solution, the presence of the hydrophobic part of its molecule causes distortion of the solvent structure, which increases the overall free energy of the system (Myers, 1992). At low surfactant concentration (10^{-5} – 10^{-4} mol/l) and high speed, 1000 cSt silicone oil produced the largest drop sizes. However, at high concentrations (≈ CMC or higher), although the viscosity was one to two orders of magnitude larger, the droplet size remained approximately the same, sometimes even smaller than that obtained with lower viscosity oils. The effect of the surfactant appears to mixed with dispersed phase viscosity even at high concentrations where the surface expansion modulus is negligibly small and thus equilibrium-like behavior can be expected. The most important conclusion of the study for 10 cSt and 100 cSt silicone oils at various aqueous surfactant concentrations is that surfactant-induced interfacial rheological properties can have a significant impact on droplet size. This effect manifests itself in different ways depending on surfactant concentration, dispersed phase viscosity, and local energy dissipation rate, showing trends inconsistent with the simple claim that surfactants reduce equilibrium interfacial tension and hence drop size. For liquids with low to moderate dispersed phase viscosity (10 – 100 cSt), the average droplet size of dilute liquid–liquid dispersions increase with increasing viscosity. However, in some studies the increase observed for the mixers was found to be less pronounced than that seen in previous studies performed in stirred tanks and mixers. However, the lowest viscosity oil (10 cSt) showed the least effect, while higher viscosity oils (50, 100, 500, and 1000 cSt) showed a more significant increase in droplet size as viscosity increased in most cases. This can be explained by the relative inability of low viscosity phases to spread the effect of Marangoni stress to the drops, as discussed in the literature. This also suggests that although the Marangoni stress, schematized in figure 1 is weaker at higher viscosities, the magnitude of its effect on droplet size may be greater due to the resulting greater internal friction. A better fundamental understanding of how surfactant convection to the interface affects surface rheology is needed. The fact that a diffusion-based approach correlates drop size data well indicates that convection is not necessarily the dominant transport mechanism as is sometimes suggested. From a physicochemical hydrodynamics perspective, it can be shown that over the wide concentration range of this study, diffusion can never be neglected as a transport mechanism for surfactant molecules from the bulk phase to the interface (Padron and Aldana, 2005).

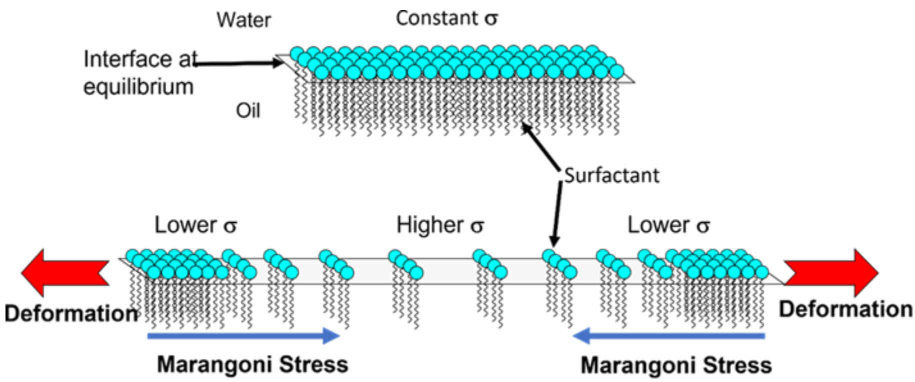

Figure 1. Effect of Marangoni stress on drops (Padron and Calabrase, 2023)

When aqueous surfactant solutions are sprayed, the surface tension of the droplets is not in equilibrium and changes as the surfactants move towards the surface, this dynamic surface tension has been reported to decrease (Christanti and Walker, 2001), resulting in an increase in the fraction of small droplets and a corresponding decrease in average droplet size (Dombrowski and Fraser, 1954; Miller and Ellis, 2000). Other authors have stated that surfactants do not affect the droplet size distribution due to their relatively slow dynamics (Kooij et al., 2018). Ellis and Tuck (1999) found that the effect on droplet size was not the same for different nozzles and surfactants. Other articles have stated that surfactants can increase the average droplet size and even suppress small droplets (Oliveira et al., 2013; Al Heidary et al., 2014). A complete understanding of the effect of surfactants on sprays is still clearly lacking (Sijs et al., 2019). During liquid droplet disintegration in spraying, it is exposed to high deformation rate flows while rapidly forming a new surface (Christanti and Walker, 2001). Immediately after the new surface is produced, the liquid will have the same surface tension as water. Surfactant molecules then move to the newly created surface area, reducing surface tension. When the surface is filled with molecules, the surface tension reaches its equilibrium value. During sputtering, the liquid is exposed to flows with high deformation rates, where a new surface is created. Dynamic surface tension states that immediately after a new surface is formed, the surface tension is the same as that of water and decreases over time. It was concluded that surfactants affect the droplet size distribution of sprays only to the extent that they cause a small reduction in average droplet size (Sijs et al., 2019).

Drift reducing adjuvants increase the viscosity of the liquid. High viscosity becomes a critical problem during pesticide operations. This is also a problem for applications that exhibit very high viscosities due to low temperatures. Because much more pumping energy is required in the turbulent flow regime. When the Reynolds number is higher than 2300, the flow is turbulent (N_R > 2300), resulting in an irregular flow in all directions and significant energy loss. Therefore, it requires much more pumping power to transport fluids under turbulent flow regime (Tao, 2016). In addition to reducing drift in high viscosity spray applications, more pressure is required to achieve effective performance. This causes increased turbulence of the spray liquid along the transmission line. Flow under laminar conditions is more energy efficient than turbulent conditions. For example, under laminar flow conditions, a 30% increase in liquid flow rate requires a 30% increase in pumping pressure. In turbulent flow conditions, it requires a pressure increase of 58.3%. This means that the pump must provide 94.3% more power (Tao, 2016). As seen in figure 2 a common practice in this field, drift-reducing agents (i.e. polymer-based chemical additives) are added to the liquid before pumping it through transmission lines to suppress turbulence. However, the addition of drift-reducing agents increases the viscosity of the fluid and this has no effect on laminar flow (Zakin, 2009). Thermal methods to reduce the viscosity of the spray fluid cannot suppress turbulence. As the temperature increases, the viscosity of the liquid decreases, the Reynolds number increases and, as a result, turbulence increases. Technologies to reduce the viscosity of the spray liquid, such as the use of surfactant, cannot simultaneously reduce viscosity and suppress turbulence. Since turbulence always starts from eddies and expands perpendicular to the flow direction, it is necessary to increase the output of the liquid by decreasing the viscosity of the liquid along the flow direction while increasing in the direction perpendicular to the transmission line axis. In other words, the viscosity of the liquid must be anisotropic (Tao, 2016).

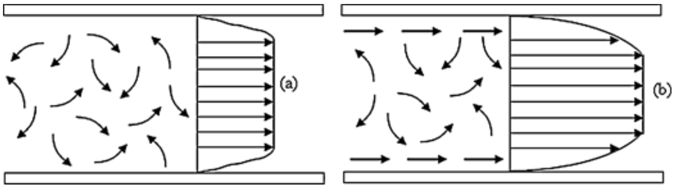

Figure 2. Velocity profiles of turbulent flow of (a) a pure liquid and (b) a liquid containing a polymer additive (Nesyn et al., 2012)

Possibilities for improving the rheological properties of the spray liquid

In general, adjuvant manufacturers claim that as the viscosity of their products increases, droplet sizes also increase, reducing the likelihood of pesticide drift. Viscosity is also important in terms of factors such as the adhesion of adjuvants with various formulations used in pesticide application after spraying on the target surface, their distribution on these surfaces and the presence of distribution uniformity. In research on the effectiveness of spraying liquids, it is common to think that liquids with high surface tension have high viscosity. Or there is a general belief that viscosity is what determines the level of surface tension. However, water with high surface tension has low viscosity. When viscosity and surface tension are evaluated together, it should be taken into consideration that the two properties are different. Surface tension results from surface molecular forces, and viscosity is related to the internal friction of molecules. Viscosity and surface tension are important properties of liquid.

Additives flow model descriptions are experimental and very complex. Some theories have been put forward regarding this. However, the approaches cannot fully explain the functioning. Studies are mostly related to the results of individual use of additives. Studies are mostly related to the results of individual use of additives. The drops formed in most of the classical type nozzles that are widely used today have a tendency to drift with the wind (Soysal and Bayat, 2006; Güler et al., 2007). The rheological properties of the system are a reflection of the mechanical properties of the individual polymer chains and the number of chains in the bulk solution.

However, even in such dilute systems, the mechanical properties of the individual chains and hence the bulk solution depend largely on the type of flow. The use of polymer additives has been shown to increase spray deposition and retention on a plant surface. A small amount of flexible polymer added to the aqueous phase can prevent drop rebound by increasing extensional viscosity (Bergeron, 2003). The surface tension and shear viscosity of the solution are not affected by these polymers. Stretching such solutions opens and deforms the polymer molecules, which consumes the energy of the drop. Splash is reduced as extensional viscosity stabilizes the capillary instabilities responsible for disintegration. Polymers are added to provide greater mobility control. Polymer solutions also have a large effect on atomization by stabilizing perturbations that drive jet fragmentation (Mun et al., 1999). Addition of polymers to the spray solution increases VMD, reduces the rate of fine drops and increases application efficiency (Jones et al., 2007). The use of such additives therefore also reduces the potential for application drift. Due to their special viscoelastic properties, polymeric additives strongly affect turbulent flow properties even when used in small amounts (Sadicoff et al., 2000). The selection of polymeric additives for a potential application is related to the unique properties of the polymer, including polymer structure, molecular weight, and fluid properties (Bhambri et al., 2016; Zivdar et al., 2005). The selection of polymeric additives for a potential application is related to the unique properties of the polymer, including polymer structure, molecular weight, and fluid properties (Bhambri et al., 2016; Zivdar et al., 2005).

Electrorheological Effect

Applying a strong electric field to a small section of the transmission line causes polarization of suspended particles present in the liquid phase and aggregates them into short chains along the direction of flow. This application of electrorheology differs significantly from conventional electrorheology fluids, where the applied electric field is perpendicular to the flow direction, leading to increased effective viscosity and even solidification of the electrorheology fluids (Winslow, 1949). As seen in Figure 3, the applied electric field and the assembled chains are in the direction of flow.

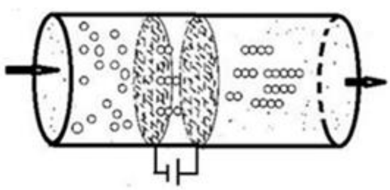

Figure 3. Aggregation of suspended particles into short chains under the influence of a local electric field (Tao, 2016)

Such aggregation effects the reduction of viscosity along the direction of flow and the significant increase of viscosity in the direction perpendicular to the flow, breaking rotational symmetry and making the fluid viscosity anisotropic, achieving two goals. These viscosity changes suppress any eddies and rotational motions, thus turbulence is suppressed, which increases flow parallel to the horizontal axis of the pipeline. This technology is environmentally friendly. It is also energy efficient as it only collects the particles and does not heat much of the liquid phase. Neutron scattering experiments and field tests on pipelines fully support the theoretical approach of this technology (Tao, 2016).

Electrorheology is effective in simultaneously reducing viscosity and suppressing turbulence. Laboratory experimental work and field tests show that electrorheology technology efficiently induces aggregation of suspended particles in liquid. These aggregated particles form short chains along the flow direction, simultaneously reducing the viscosity of the liquid and increasing flow output by suppressing turbulence. It becomes turbulent when the Reynolds number exceeds 2300. With electrorheology, the fluid remains laminar even at Reynolds numbers close to 10,000. Additionally, field tests show that the electrorheology effect on the viscosity and flow properties of the liquid lasts for 11 hours after the electrorheology process ends (Tao, 2016). Electrorheology technology shows great potential for pulverization operations. However, these applications require significantly more research.

Effect of Dynamic Surface Tension

The volumetric average droplet size of a spray depends solely on the surface tension of the liquid. In general, a lower surface tension results in a decrease in volumetric average droplet size. (Kooij et al., 2018; Ellis et al., 2001). Because when the surface tension is lower, it becomes easier for small drops to form (Kooij et al., 2018). However, the important point is that when surfactant-based adjuvants are sprayed the surface tension of the droplets is not in balance and changes over time as the surfactant molecules migrate to the surfaces of the newly formed droplets. Equilibrium surface tension is a dynamic parameter of surface tension that varies significantly throughout droplet breakage. During spraying, fluids are exposed to flows with high deformation rates as droplets break up and new surfaces are rapidly formed (Christanti and Walker, 2001). The typical time scale for surfactant adsorption varies roughly from 100 to 1000 ms, depending on the type and bulk concentration of the surfactant. The second characteristic time is the characteristic time for the creation of new surfaces. We can accept this as the time during which the layer breaks down after leaving the breast. During the disintegration of surfactant droplets, new surface area is rapidly created. Surfactant molecules need time to move to the newly created surface, resulting in a time-dependent surface tension. Assuming that a time of 20 ms is needed at the moment of droplet breakage of the surface, as suggested by Hewitt et al., (2002), and replacing the equilibrium surface tension with the dynamic surface tension at the moment of breakage, the volumetric average droplet size, concentrations and types of spray nozzles of the tested adjuvant series can be estimated It has been evaluated to help (Sijs and Bonn, 2020).

Application of nanoparticles in surfactant use

Nanoparticles are generally defined as particulate matter with sizes or diameters ranging from 1 nm to 100 nm (Auffan et al., 2009; Boverhof et al., 2015). Many studies have reported the use of clay, silica/fumed silica, aluminum oxide, zinc oxide and titanium oxide nanoparticles to modify the interfacial properties of liquids (Cheraghian, 2017; Cheraghian, 2016b; Cheraghian and Tardasti, 2012; Gbadamosi et al., 2019a; Rezk and Allam, 2019; Sharma et al., 2016; Zargar et al., 2020). Nanoparticles provide some additional advantages when incorporated into surfactant-assisted spraying liquid. Experiments in a glass micromodel have shown that the results in the presence of nanoparticles provide smoother flow patterns as well as a more stable state compared to the absence of nanoparticles (Betancur et al., 2020; Li et al., 2020c; Liu et al., 2020b; Wu et al., 2017; Zhong et al., 2020; Cheraghian, 2016a). Such results show that nanoparticles have the ability to improve the rheological properties of fluids injected during processes (Massarweh and Abushaikha, 2020). Nanoparticles can be used to stabilize foams such as those containing CO_2 (Horozov, 2008).

In some studies, drift-resistant drops with low viscosity have been produced (İtmeç et al., 2022). There are some approaches to describing spray flow characteristics. These theories cannot fully explain flow effects. Spraying performance can be increased by transforming the short-chain micelle structure by affecting the long micelle structure formed during flow by the electrical magnetic field created in the transmission line section close to the spray tip. In addition, in a conventional application, the long-chain micelle structure formed by the additives has the possibility of improving spraying capabilities by providing the formation of short-chain micelles with the sudden shear effect of the liquid, depending on the position of the turbulator placed behind or in front of the nozzle. On the other hand, in plant protection applications, the engine reaches the regime temperature while the tractor is working in the field. The heat energy released from the exhaust is at different levels at different engine loads and speeds (Toraman, 2021). Spray transmission pipes are contacted along the tractor exhaust pipe line. Thus, the spraying liquid is used for effective control in agricultural control by reaching the desired high temperatures according to the application area and changing its viscosity and other physical properties.

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CHAPTER IX

EFFECTS OF SURFACTANTS ION STRUCTURE ON SPRAY PROPERTIES

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INTRODUCTION

In addition to increasing production opportunities by taking advantage of developing technologies in order to achieve high efficiency in agriculture, we also combat diseases and pests encountered during cultivation. Among plant protection methods, chemical control methods are widely preferred because they are economical and provide easy and effective results. Some additives are added to the pesticide formulations of the sprayer tank to increase the effectiveness of the pesticides used. Additives perform by changing some properties of pesticides depending on their intended use in order to increase pesticide efficiency. The most commonly used additives are substances such as surfactants, compatibility agents, bufferers, defoamers, thickeners, anti-drift, colorants, and suspending agents (Hock, 2022; Soysal and Bayat, 2006; Özlüoymak, 2022).

Water is mostly used as a carrier in pesticide applications. Among the additives, surfactants are widely used, which change the physical properties of the spray liquid and improve its adhesion, spreading and adhesion abilities on the target surface. Surfactants reduce the surface tension of the application liquid and increase spraying effectiveness by improving drop diameter formation, uniformity on the target surface, increase in spray angle, and penetration. Surfactants also perform by binding according to the interaction between the ionic charges they have and the molecular charges of the sprayed leaves. Surfactants are classified according to their ionic structures as anionic (negatively charged), cationic (positively charged), nonionic (uncharged), amphoteric (positively or negatively charged depending on the pH of the environment). Surfactants are widely used as emulsion aids in plant protection products (Green, 1992; Bayat and Zeren, 1999).

The relationship between pesticides and the leaf surface is much more complex than just reducing the surface tension of the pesticide solution. Molecules of surface tension reducers also change the permeability of the cuticle. Surface tension reducers also serve as bridges between incompatible chemicals, such as oil and water, or water and wax on leaf surfaces (Tadors, 2005; Foy, 1993).

Which group of surfactants belong to is important, especially in the selection of pesticides with which they are used. While anionic surfactants are more effective in contact-acting pesticides, nonionic surfactants are used mostly in systemic-acting pesticides because they help the penetration of pesticides through the plant cuticle. Cationic surfactants cannot be used alone because they are phytotoxic to plants, and amphoteric surfactants are expensive (Lorenz, 1999).

EXPERIMENTAL STUDIES

Surface tension

For the research, among the additives sold in the market, 5 each of anionic and nonionic surface active additives were used for sprayer tank mixtures, according to their ionic structures. The chemical contents, usage dosage, and ionic structure properties of the adjuvants are listed in Table 1. In the preparation of application solutions, mixtures were made with pure water according to label recommendations.

Table 1. Properties of surfactants

Ion	Active ingredient	Dose
Aniyonik	Faty asit ve polialkol	2.5 mL L^{-1}
	Sodiumcarboxilmetylcelulos	0.3 mL L^{-1}
	Sodiumcarboxilmetylcelulos	0.5 mL L^{-1}
	Carboxymethylcelluse	1 mL L^{-1}
	Sodyum dikotil sülfosuksinat	0.5 mL L^{-1}
Noniyonik	Reçine	1 mL L^{-1}
	Trisiloxane alkoxylates	0.4 mL L^{-1}
	Polyalkaleneoxide - heptamethyl trisiloxane + Allyloxypolyethyleneglycol	0.2 mL L^{-1}
	Alcohol ethoxylate, alkylphenol ethoxylate	1 mL L^{-1}
	Alkilpoliglikoleter	0.5 mL L^{-1}

Seven different plant leaves were used to determine the adhesion, spreading and wetting levels of the spray solution prepared with the surfactants used in the research on the applied leaf surfaces. When selecting leaves, plants with hairy surfaces, those without hairs on the surface, and plants with wax and those without a wax layer were preferred. The leaves used in the experiments were selected according to their genus characteristics. *Habiscus esculentus*, *Citrus sinensis*, *Citrus limon*, *Lycoperslcon esculenlum*, *Solanum melongena L.*, *Capsicum annum*, *Vitis vinifera* leaves were used in the research. The leaves used in the research were taken from the phenological periods of *Habiscus* *esculentus* BBCH=67, *Citrus sinensis* and *Citrus limon* BBCH=81, *Lycoperslcon esculenlum* BBCH=19, *Solanum melongena L.* BBCH=73, *Capsicum annum* BBCH=19 and *Vitis vinifera* BBCH=71 (Meier, 2001).

Drop Shape Analysis 10 (DSA 10) device produced by Krüss company was used to determine the values such as surface tension of the drops obtained from mixtures prepared with surfactants, contact angles on the leaf surfaces, spreading and adhesion rates.

Contact angles

To determine the contact angles of surfactant mixtures prepared with water, they were applied to each leaf surface ten times. The contact angles of the formed drops were determined for the 3rd and 10th seconds. Adhesion data were taken from the contact angles formed on the leaf surfaces in 3 seconds. The amount of spread and wetting to the surface was determined according to the results of the contact angles formed at the end of the 7 seconds between the 3rd and 10th seconds.

Foam Measurement

To determine the foam levels created by surfactants, a copper butterfly fan was mounted in a 500 mL glass measuring tube with a bearing and shaft. It was moved by being fed from 18 volt DC 25,000 rev-1 power source as the energy source. An optical tachometer (Wellhise Ht522) was used to determine the number of revolutions.

EXPERIMENTAL RESULTS

Surface tension results

Water is mostly used as a carrier in agricultural pesticide application. Water molecules are formed by the union of one oxygen and two hydrogen atoms in a regular tetrahedral geometry, with non-neighboring hydrogen atoms forming polar covalent bonds at an angle of 104°. In this case, water molecules have a dipole structure because the electrons are not shared equally. Electricity distribution around the water molecule is not homogeneous. On the oxygen side of the structure, the electron density is high and has a negative charge (-), while on the hydrogen side, the electron distribution is relatively low and has a positive charge (+) (Megep, 2016; İtmeç et al., 2022). Surfactants have the ability to accumulate in solution or at interfaces, forming micelles at the liquid-gas interface, aqueous solutions, and structured films. Soluble surfactants attract interfaces that are in equilibrium with their mass. This property is known as adsorption.

Elucidation of ionic surfactant adsorption mechanism at air-liquid interfaces, thin film stability, micellization, foamability, etc. It is important for various practical phenomena such as. However, the theoretical explanation of this mechanism is complex. Because solutions of ionic surfactants are by nature multicomponent systems. They contain surfactant ions, counterions, salt ions to control the ionic strength or pH of the solution. Moreover, it is known that the hydrolysis of ionic surfactants or the adsorption of ionic surfactant is strongly affected by the structure of the adsorbed phase, especially the electric double layer (EDL) that arises due to surfactant ion adsorption (Dukhin et al., 1995). These properties are related to the thickness of the adsorbed (Stern) layer (Figure 1) where the surfactant head groups are located, the degree of penetration of the Stern layer by counterions, the distribution of electric dipole moments in the adsorbed layer and the dielectric characteristics. These parameters are difficult to measure in most cases. As a result, there is relatively little data available to formulate any general ionic model (Para et al., 2003).

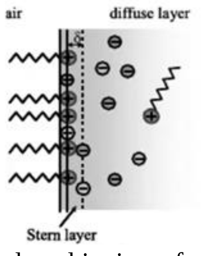

Figure 1. Schematic view of the developed ionic surfactant adsorption model (Para et al., 2003)

Adsorption of ionic surfactants at the air/electrolyte interface leads to the formation of EDL. Surfactant head groups are adsorbed at the interface in the Stern layer. Counterions of any type can penetrate the Stern layer. The extent of this penetration depends on the effective size of the introduced counterions and their interactions in the Stern layer. All ions, surfactants and counterions in the Stern layer retain their freedom of movement. The Stern layer can be considered as a two-dimensional electrolyte that does not meet the electroneutrality condition. In the case of anionic surfactant, the total charge in the Stern layer, which determines the diffusing layer potential, is the sum of the negative charges of the adsorbed surfactant groups and the positive charges of the counterions, Figure 1 (Para et al., 2003).

Several attempts have been made to relate in an empirical or semi-empirical manner the surface tension of different ionic liquids with the properties of their constituent ions. The development of a general framework to explain and predict the surface tension trends of a large number of different ionic liquids appears difficult due to the complex structural nature of ionic liquids (Kolbeck et al., 2010). Ionic liquids are known to exhibit complex structure and nanoseparated domains, which are a result of the balance that must be achieved between local electroneutrality conditions between oppositely charged ions and the competition between electrostatics and other van der Waals forces. Most solid materials acquire a charge due to preferential absorption of ions or dissociation of surface groups when immersed in a liquid medium. These surface charges are balanced by a diffuse layer of oppositely charged counterions present in the liquid, giving rise to an electrical double layer. The repulsive force between these two charged surfaces arises due to the mutual repulsion between the counterions (Figure 2) (Kunz et al., 2004). The difference between ionic parameters (size, polarizability and ionization potential) exists at different levels on the surfaces of surfactants. Thus, it affects the interaction between colloids (surfactants, etc.) differently. For example, Ninham et al., (2001) explained the van der Waals interaction between inorganic ions and the interface, thus determining the concentration profiles of different ions, but encountered more difficulties (Bostroem et al., 2004; Tavares et al., 2004).

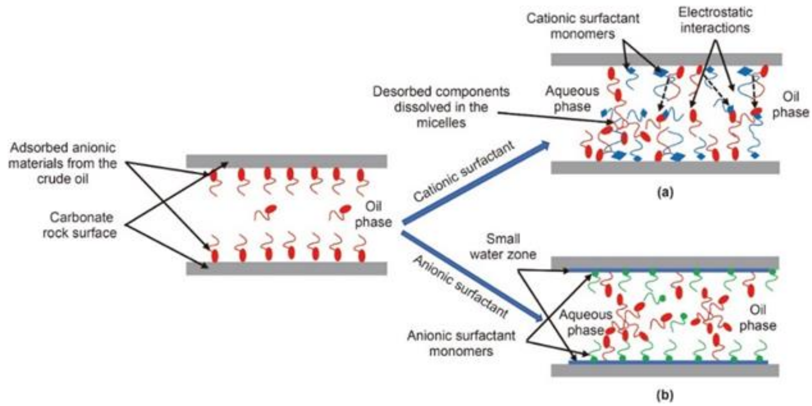

Figure 2. (a) Cationic surfactant (ion pairing mechanism) and **(b)** anionic surfactant (surfactant adsorption mechanism) (Standnes and Austad, 2000)

According to the scheme of wettability change of carbonate rock, studies confirmed that ionic surfactant changes the wettability of carbonate rock through the mechanism of ion pair formation between negatively charged carboxylates. In the absence of electrostatic interaction, the surfactant adsorption mechanism altered the wettability of carbonate through the replacement of hydrophobic substances adsorbed on the solid surface with hydrophobic groups of nonionic or anionic surfactant molecules (Standnes and Austad, 2000; Hou et al., 2016; Jarrahian et al., 2012). The effect of electrolytes on the micellization process for nonionic and anionic surfactants has been experimentally evaluated. Bu sonuçlar moleküler yapıdaki eten oksit (EO) gruplarının sayısı arttıkça iyonik olmayan yüzey aktif maddeler için CMC değerlerinin düştüğünü göstermiştir. Additionally, CMC values for anionic surfactants were found to be higher than for non-ionic surfactants due to the presence of electrostatic repulsion between head groups (Standnes and Austad, 2000).

The surface tension values created by mixtures prepared with surfactants are shown in Figure 3. The surface tension of the solutions prepared with anionic surfactants was reduced from 73.21 mNm^{-1} to 52.64 mNm^{-1} compared to water, and with nonionic surfactants it was reduced to 27.78 mNm^{-1}. While the surface tension of water was reduced by approximately 1/3 with anionic surfactants, nonionic surfactants reduced the surface tension of water by an average of 2/3. The results obtained are similar to other studies (Toraman and Bayat 2015).

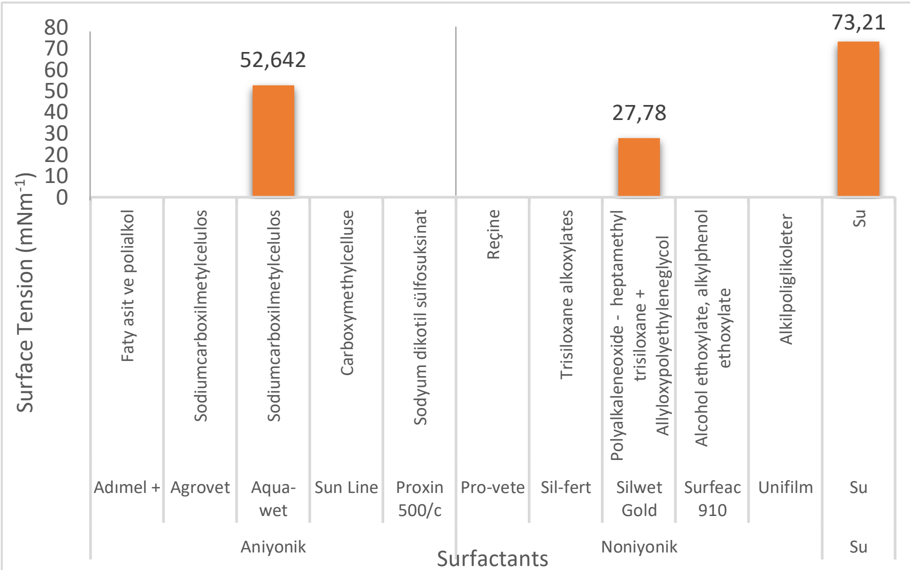

Figure 3. Surface tensions of surfactants according to their ionic structures

Non-ionic surface tension reducers, consisting of uncharged molecules, have a hydrophilic (water-loving) structure and are the most compatible with pesticides among the surfactant groups, and therefore the most used group (Lorenz, 1999; Penner, 2000; Tu and Randal, 2001). Nonionic surfactants have a polar head group that has a strong affinity for water and does not ionize in solution. Non-ionic surfactants are affected by hydrogen bonding and van der Waals interactions (Kamal et al., 2017). Therefore, it can be said that nonionic surfactants create lower surface tension values.

Since the surfactant adsorption rate is affected by surface charges, which vary depending on the pH situation, pH is one of the factors affecting the surfactant flooding efficiency. The point of zero charge (PZC) is the pH value at which the net charge on the surface (surface charge density) is zero. This is a basic feature. Because at pH levels higher than their PZC surfaces develop a negative charge (Grigg et al., 2004).

Surface tension depends on the surface concentration of the surfactant anion but is not controlled by the types of counterions. The counterion can, in fact, affect the surface tension of the solution, but its effects are exerted indirectly by changing the surface concentration of the surfactant ion. The larger dissolved counterion has the ability to neutralize the aggregate opposite charges produced by the adsorbed surfactant ion in the surface layer. Therefore, by preventing further accumulation of surface active ions, the solution containing this ion may have a relatively lower surface tension under the same mass concentration (Wang and Morgner, 2014).

Contact angles created by surfactants on leaf surfaces

The interaction between solid surfaces and surfactants has been elucidated with the help of atomic force microscopy (Manne and Gaub, 1995). In a study conducted with trisiloxane mixtures prepared at 0.5% or 1% (w/w), it spread over a smaller area at 52% relative humidity than the mixture prepared at 0.1% (w/w) concentration. At first, the spreading area increased with increasing concentration, but after a ratio < 0.1% (w/w), it started to decrease again. However, as the concentration increased at 100% relative humidity, an increase in the spread area was also observed. When looking at the spreading area as a function of time for different concentrations, it was determined that at concentrations above 0.1% (w/w), the spreading speed at the beginning of the spreading process was independent of the concentration of the surface tension reducer. However, after 10-20 seconds (depending on concentration) the spreading process suddenly stopped. At this point, in a diffusion experiment performed on the analytical balance, it was determined that 10% of the water had evaporated. This means there is enough water for diffusion to occur. Accordingly, it can be said that the reason for the cessation of spread was not evaporation, but perhaps a secondary factor. This creates a layered phase dispersed on the surface or provides high viscosity formation that prevents the spread of drops. This interpretation is supported by the observation that the effect of relative humidity is highly expressed with surfactants with an even larger layered phase, such as the trisiloxane derivative-like (with acetyl end group) (Venzmer and Wilkowski, 2006).

It has been observed that trisiloxane mixtures, whose liquid surface tensions are very close to each other, spread in different sizes on solids with constant surface energy. In studies conducted on the reasons for the different spreading areas formed by trisiloxsan mixtures with the same surface tension

(Venzmer and Wilkowski, 2006), it has been suggested that the interfacial tension causes the formation of different spreading areas on the same solid surfaces of trisiloxsan component liquids, whose surface tensions are very close to each other, according to Young's equation. Interfacial tension cannot be measured directly. For this purpose, the contact angles of the drops formed on the surfaces are used. However, in these systems, all trisiloxane additives create very low contact angles and do not provide a method to distinguish between them. For this reason, evaluations were made by taking into account a simple but effective concept that predicts the aggregation of surface tension reducers in solution, according to the previously explained molecular structure formation. In this model, determinations are made according to the formed shape of the surfactant molecules according to the P coefficient, which is the ratio of the hydrophobic and hydrophilic parts of the molecule (Israelachvilli et al., 1976). Accordingly, if the hydrophilic head part is larger than the hydrophobic part ($P < 1$), the surfactant causes the molecules to shrink in a spherical or cylindrical shape. If the hydrophilic head part is equal to the hydrophobic part ($P \approx 1$), the spontaneous average slope of these molecules becomes zero and the surfactant results in the formation of a flat bilayer (Mitchell et al., 1983). When the cylindrical or spherical micelles formed by surfactant adhere to a hydrophobic surface, they spread by splitting on the surface. This arrangement forces the hydrophilic head in contact with the hydrophobic surface to have a lower than ideal interfacial tension. Conversely, when the P coefficient is equal to 1, a curved aggregate structure does not form. Instead, a uniform spread on the substrate surface is observed. In this case, the hydrophobic parts of the surfactant are in contact with the solid surface. Therefore, the surface tension occurring at this interface can be expected to be lower with micelle-forming surfactants. On a hydrophilic surface, the micelles have more hydrophilic head parts, so they cling to the surface, ensuring the interfacial tension is close to ideal. Conversely, a high HLB value encourages the formation of interfacial tensions that will produce greater results on different surfaces.

The mechanism of spread, can be expected to reflect the kinetics of spread itself. Therefore, during the first 10 seconds of the spread process, the spread rate was monitored as a function of its concentration. The same intriguing kinetic dependence is observed with all superspreaders. First, at low concentrations, the spread rate is proportional to the concentration of surfactants. But above a certain limit (0.1% w/w), the rate becomes constant. This kinetic behavior can only be explained by the existence of two rate-determining processes. First, at low concentrations, the rate of spread is limited by the means to transport surfactant aggregates, which is proportional to the aggregate concentration. Above a certain limit, the amount of active substance on the surface is not decisive. At this point, the transformation of double-layered flat-structured surfactant aggregates into a single-layer structure limits the spread rate. This interpretation of kinetic data can be confirmed by comparing static and dynamic surface tension as a function of concentration (Venzmer and Wilkowski, 2006).

The drop contact angle values formed in the 3rd second by applying mixtures of surfactants and pure water to seven different leaf surfaces are shown in Table 2. According to the results obtained, the levels of surfactants to improve the ability of water to adhere to the target leaf surface were determined. The average contact angle formed by water droplets on leaf surfaces was determined as 91.1°. The threshold degree of contact angles is stated as 80° angle. The wetting property of water is due to its cohesion feature, which can adhere to many substances due to the attractive force of water molecules (Megep, 2016).

Table 2. Contact angles (°) created by surfactants on the leaves in the 3rd second

	Water	**Adimel**	**Agrowet**	**Aquawet**	**Prowet**	**Proxin**	**Silfert**	**Silwet**	**Sunline**	**Surfeac**	**Unifilm**
Habiscus esculentus	87,8	41,8	100,4	86,2	69,2	63,7	69,0	35,0	72,4	32,8	71,9
Citrus sinensis	86,3	45,8	54,1	82,1	74,2	85,3	49,1	43,1	82,9	43,2	67,1
Citrus limon	72,9	43,4	75,2	94,1	61,1	55,8	54,6	31,5	66,0	60,2	75,4
(Lycoperslcon esculenlum	100,0	49,0	94,8	100,1	84,1	73,7	46,9	56,6	99,5	46,7	85,3
Capsicum annum	81,8	43,7	87,1	83,8	79,0	73,5	72,6	35,6	77,6	45,5	72,4
Solanum melongena L.	95,2	53,5	86,7	91,3	85,1	68,0	77,4	43,3	93,1	47,5	74,5
Vitis vinifera	114,0	42,6	96,5	115,7	105,6	97,5	94,1	45,7	110,1	54,5	100,7

It was determined that droplets in both ion structures formed low contact angles. The average contact angle of the mixtures prepared with anionic surfactants on the surfaces was 75.6°, improving the adhesion properties of water and creating lower contact angles. The drop contact angles created by nonionic surfactant solutions have increased the adhesion performance significantly. It can be said that nonionic mixed drops provide the formation of drops that are resistant to flow (Figure 4).

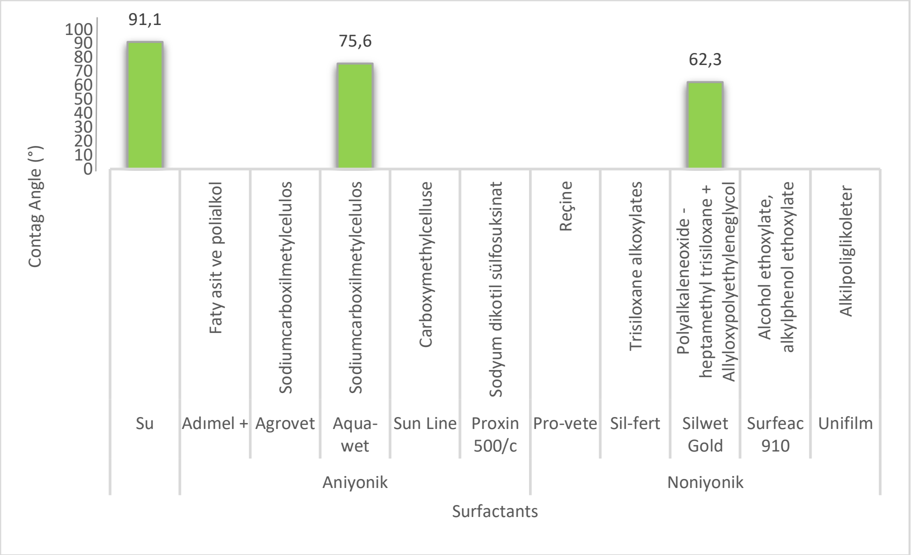

Figure 4. Contact angles created by surfactant solutions on leaf surfaces in the 3rd second

The reduction levels in drop contact angles created by mixtures prepared with surfactants on leaf surfaces after 7 seconds are shown in Table 3. After determining the contact angles formed by the drops applied to the target leaf surface within 3 seconds, the drop contact angles formed on the leaf surfaces at the end of the 10th second were evaluated as the adhesion speed within 7 seconds (Toraman and Bayat, 2019). At the end of 7 seconds, according to the amount of decrease in the contact angles formed by the droplets (Figure 5), the adhesion rate of the water droplets remained low, with a minimum angular decrease of 1.8° on the leaf surfaces. Anionic surfactants increased the sprread rate of water on surfaces and improved adhesion properties by 5.5°. The spread of solutions prepared with nonionic surfactants on leaf surfaces was very rapid, with an increase of 9.4°. It can be said that the nonionic surfactants used as super spreaders increase the spreading and adhesion performance of the spray liquid to a high extent, have a high probability of increasing the drug effectiveness in pesticide applications, and will increase the permanence effect on surfaces in rainy weather.

Depending on the optimal interaction of the polar or nonpolar part of the surfactants with the surface, different structures of the adsorbed surfactant layer are formed. In general, a monolayer structure is found on hydrophobic surfaces, and different forms of surface aggregates such as micelles or bilayers are found on hydrophilic surfaces (Zhu et al., 1991).

There are basically two important differences between the behavior of micelles and double-layer flat structured surface tension reducers formed at the air and water interface. In a system containing micelles, a surfactant is in equilibrium between single molecules in solution and a monolayer of surfactantformed at the air/water interface, forming thermodynamically stable aggregates. In the case of a double layer such as a vesicle, these aggregates are not thermodynamically stable. When the vesicle-shaped surfactant comes into contact with the surface, the vesicle suddenly bursts and a large amount of surfactant accumulates on the surface. In this system, surfactants are concentrated at the air/water interface because they are more hydrophobic and less soluble. Therefore, surface tension reducers form a system that allows molecules to spread at interfaces with high concentration.

The adsorption of surfactants at solid–liquid interfaces is strongly influenced by a number of factors, such as surface properties (particle size, porosity and chemical composition), molecular structure of the adsorbed surfactant (whether it is a mixture or a single component). Ionic or non-ionic, hydrophobic group straight or branched, long or short, etc. and the environment of the aqueous phase (pH, electrolyte content, etc.), together with all these factors, determine the mechanism by which the adsorption of the surfactant from the aqueous solution onto the solid occurs, as well as the efficiency of the surfactant adsorption (Rosen, 2004).

Adsorption of a monolayer of surfactants on a hydrophilic surface in the presence of an adsorbed monolayer at surfactant concentrations lower than CMC increases the surface attractive forces, making it hydrophobic (hydrophobic effect). It has been stated that if the surfactant concentration is increased, the attractive force is expected to decrease again due to the formation of double layers and other complex aggregates (Kyraly et al., 1997).

Table 3. Contact angle decrease (°) created by surfactant drops on the leaves in 7 seconds

Bitki Türü	**Water**	**Adımel**	**Agrowet**	**Aquawet**	**Prowet**	**Proxin**	**Silfert**	**Silwet**	**Sunline**	**Surfeac**	**Unifilm**
Habiscus esculentus	3,8	11,0	11,2	9,9	7,0	9,1	9,9	14,9	4,7	5,7	9,3
Citrus sinensis	1,5	8,2	2,0	0,4	2,4	5,0	10,9	13,7	0,6	8,0	4,0
Citrus limon	1,5	6,7	5,0	1,3	12,0	3,2	11,9	9,8	3,6	8,6	2,6
(Lycoperslcon esculenlum	0,7	18,8	5,0	1,7	6,8	13,8	12,9	4,8	1,7	13,5	5,7
Capsicum annum	1,5	10,7	2,3	1,9	4,8	4,4	13,9	20,1	2,2	12,0	6,3
Solanum melongena L.	1,2	13,8	10,0	2,3	6,8	4,8	14,9	15,6	6,1	7,5	7,0
Vitis vinifera	2,4	3,7	1,0	2,8	4,6	3,8	15,9	6,6	1,5	8,7	9,7

In general, it has been found that nonionic surfactants can wet and stabilize better than anionic surfactants in aqueous media. The reason is explained by the molecular structure and micellar properties of surfactants. In aqueous media, ionic surfactants have much higher CMC than non-ionic surfactants containing equivalent hydrophobic groups. The CMCs of nonionics are significantly lower than those of single species containing the same hydrophobic group and containing oxyethylene. This is because the component with low oxyethylene content lowers the CMC more than the components with high oxyethylene content raise it. Addition of inert salts to an aqueous surfactant solution generally reduces the CMC of ionic surfactants. This effect is less pronounced when the surfactants are nonionic. Salts tend to screen electrostatic repulsions between head groups and effectively make the surfactant more hydrophobic. This increases hydrophobic interactions between surfaces, causing them to aggregate at a lower concentration, thus reducing CMC (Lange,1999). Shinoda and Arai (1965), studied different binary system (surfactant-hydrocarbon) and found that the solubility increased as a function of decreasing the ethoxyethylene chain length of the surfactant (Alejandra and Trosell, 2005).

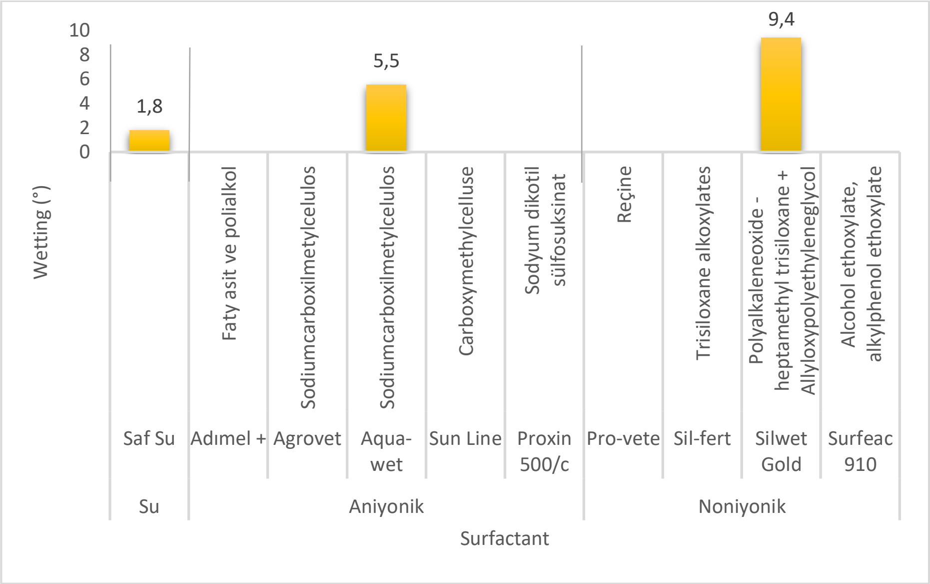

Figure 5. Contact angles formed by surfactant solutions on leaf surfaces in 7 seconds

Spray pattern

The application width was determined by spraying surfactant mixtures onto the paternator surface at a fixed height from a Gündüzler G112 1.2 mm hollow conical jet single nozzle. In order to determine the effects of surfactants on the spray pattern, the operating conditions of the variables in the applications were kept constant in each application. It was determined that when water was applied alone, the spray liquid collected in the center (Figure 6). In the spray pattern prepared with anionic surfactant solutions, central accumulation was improved and a more uniform distribution was achieved. The pattern formed by the mixtures prepared with nonionic surfactants provided a relatively more regular distribution (Toraman and Bayat, 2016).

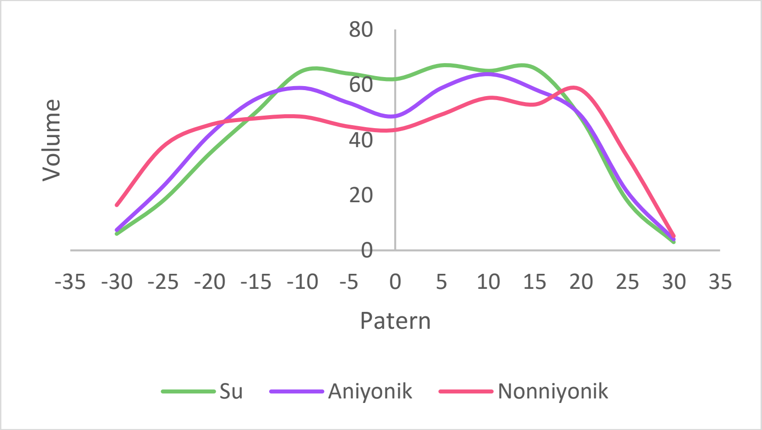

Figure 6. Spray pattern created by surfactant mixtures

Foam formation

Spraying liquids prepared with surfactants are continuously mobilized through the mixer unit in the sprayer tank to achieve a homogeneous spraying and cause foam formation as the tractor moves on the field. The resulting foam causes irregularities during spraying and reduces application success. In order to determine the amount of foam formed by surfactants, the prepared solutions were mixed in the foam formation device and the resulting foam levels in the measuring tape were indicated. While anionic surfactants created an average of 14.8 mm of foam, nonionic surfactants created approximately 27 mm of foam (Figure 7). Nonionic mixed solutions created twice as much foam as anionic mixtures. Nonionic surfactants have higher surface tension values than anionic ones (Toraman and Bayat, 2016). We can say that the amount of foam formed is proportionally due to surface tension.

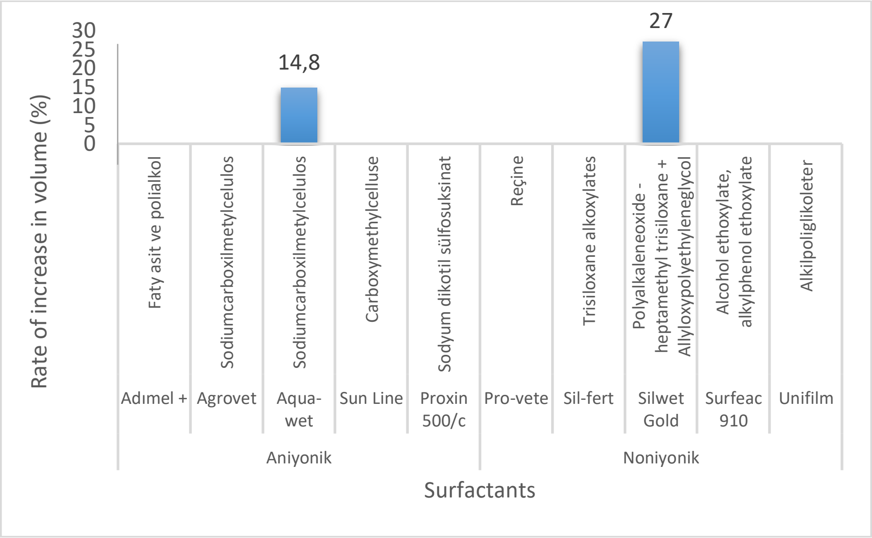

Figure 7. Amount of foam created by mixtures prepared with surfactant (mL)

RESULTS

It is common to use pesticides in agricultural production to increase productivity by protecting plant health. To increase the effectiveness of spraying, different techniques such as spraying technique, nozzle type and formulation features are used. Many additives are also used to increase pesticide effectiveness. These additives include surfactants. These additives, which have different ionic structures, increase the pesticide application efficiency by changing the physical properties of the spray liquid. In the study conducted with surfactants with anionic and nonionic structures, the effects of the spray liquid such as surface tension, spray pattern, and foam formation were examined. As for the surface tension changes of the mixtures prepared at the recommended doses, anionic surfactants reduced the value of water with a surface tension of 73.21 mNm^{-1} to 52.64 mNm^{-1}, and nonionic surfactants reduced it to 27.78 mNm^{-1}. Nonionic mixtures showed high performance in terms of the adhesion, spreading and wettability ability of the drops to the leaf surfaces. In terms of foam formation, anionic surfactants gave better results than nonionic surfactants. The surface and interfacial tensions created by ionic and nonionic surfactants have created important results by interacting with electrostatic charges on adsorption, spreading and adhesion behaviors, which are adsorption properties on solid surfaces. In general, nonionic surfactants further improve the properties of the spray liquid. In pesticide applications, technical regulations are required according to the demands of the product being grown, rather than a uniform application. For this reason, the properties of the spray liquid to be prepared should be adjusted by knowing the results of the substances to be used as additives during herbal control.

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CHAPTER X

THE PLACE OF ORGANIC AND ORGANOMINERAL FERTILIZER PRODUCTION IN SUSTAINABLE AGRICULTURE

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INTRODUCTION

The shift to intensive agriculture has become necessary in order to meet the growing food needs of the world's population, which is expected to reach 9–10 billion people by 2050 (Geographic, 2017; Hunter et al., 2017). Due to the world's limited supply of arable land, innovative strategies and tactics have been developed to boost yields per unit area. Many chemical and pharmaceutical industries started using chemicals like phosphate, sulphate, and nitrate, which were used in explosives that became more common after World War II, to produce ammonium nitrate fertilisers in the 1950s (Nutki and Nutki, 2020). Following then, the manufacture of chemical fertilizers increased quickly. Over time, the excessive use of chemical fertilisers together with intensive agricultural practices has led to a decrease in organic matter, minerals and plant nutrients necessary for healthy soil and plants. The inability of the plant to fully uptake the necessary nutrients is due to the decreasing organic matter content of the soil. Due to this situation, the plant is now more susceptible to UV radiation from the sun and harmful external agents such as insects, fungi, weeds, bacteria, etc. For this reason, the use of harmful pesticides for pest control began in the 1960s under the name of agricultural warfare.

Pests in the plant have been eliminated by the usage of pesticides. Additionally, genetic modification of the plant has begun in try to develop resistance to these chemicals. The usage of glycophate insecticide and an increase in plant genetic modification research in the following years, particularly after the 2000s, have led to a significant rise in human heart, obesity, and cancer illnesses. The amount of annual product that should be extracted from the soil decreases as a result of the increased use of chemical fertilizers, pesticides, which also cause a decrease in organic substances, essential nutrients, and trace elements (Donat and Nohum, 2016). In this case, more agricultural production will be needed in the next 50 years to meet the growing demand for food than all farmers have ever produced (Geographic, 2017). If we do not drastically increase agricultural production and significantly reduce the consumption of water, fossil fuels, chemical fertilizers, pesticides, and other resources, an estimated 1 billion people worldwide will be in direct risk of starvation by the 2050s, and humanity will face its biggest global issue to date (Korkmaz et al., 2017; Geographic, 2017).

Instead of using organic fertilizers derived from insufficient animal, agricultural, municipal, household, etc. wastes, it is necessary in this case to produce and use organomineral fertilizers, which can be produced as a process to the same extent as chemical fertilisers, in order to restore the soil that has lost its value and lessen reliance on the increasingly widespread use of chemical fertilisers, pesticides, etc. (Nahum and Donat, 2016). Organomineral fertiliser production has become widespread in the world and in our country in recent years. Currently, small and medium-sized industrial enterprises produce these fertilisers by traditional or primitive methods. Large chemical fertiliser producers in the sector (such as Hektaş, 2021; Toros Agriculture, 2023) have also started to produce these fertilisers, even with limited capacity and variety.

The annual production of chemical fertilisers in our country is 6.48 million tonnes (Gübretaş, 2021; Agriculture, 2021). The production capacity of organic mineral fertilisers is about 300,000 tonnes per year. Natural organic fertilisers, mainly obtained from animal waste and not from industrial production, are used at a level of approximately 700,000 tonnes (Nahum and Donat, 2016). As a consequence, there is scarce industrial production of organomineral fertiliser in granulated form due to a lack of systematic planning. Our nation possesses one of the largest agricultural land areas in the world. However, its fertiliser production falls below the world average, necessitating an increase in organomineral fertiliser production in line with the amount of land. At this point, alongside precision farming technologies, the increased production and use of organomineral fertilisers is essential for the continuation of sustainable agricultural production. It is a challenge to obtain the same crop yields as in previous years in today's agriculture, where chemical fertilisers are mostly used. Consequently, the usage of more chemical fertilisers is required to maintain or increase crop yields (Engin and Cöcen, 2012). With increased fertiliser usage, soil quality in terms of physical, chemical, and biological attributes deteriorates (Agrotime, 2023; Nahum and Donat, 2016). Chemical fertilisers were developed to help keep nutrients in the soil, especially on sloping land and in areas vulnerable to flooding and heavy rainfall. Although they have some advantages in this respect, they harden the soil on common flat farmland.

For optimal and successful agriculture, soils used for agriculture should contain at least 3% organic matter. This ratio is ideally between 5% and 6%

(Korkmaz et al., 2017). However, in most of the soils in our country, especially in the soils on sloping lands, the amount of organic matter is less than 1%. As a result, it is known that the soils of our country have low organic matter content. Most soils worldwide are poor in organic matter. Organic matter not only supports the physical, chemical and biological processes of the soil, but also ensures that plants can properly absorb essential nutrients (N,P,K). Chemical fertilisers do not contain organic matter. The additives included in their composition; lime, sand, chlorine, etc. harden the structure of the soil. They also lack sulphur and trace elements necessary for the functions required by the soil and the plant (Agrotime, 2023). The uptake of crucial nutrients from fertilisers by plants is crucial for their growth. However, organic matter is insufficient in the soil and decreases gradually from the use of chemical fertilisers. Consequently, plants cannot absorb surplus nutrients, leading to an increase in soil salinity and aridification of agricultural soils (Agrotime, 2017; Engin and Cöcen, 2012). Excess plant nutrients remaining in the soil can adversely affect human health when mixed with drinking water and rainfall. Today, individuals cannot get the nutrients they need from fruits, vegetables and cereals due to the decrease in their nutritional value, and they also absorb chemical pesticides. Serious diseases caused by these fertilisers are becoming widespread day by day. Therefore, instead of chemical fertilisers, organomineral fertilisers should be produced in sufficient amounts to meet the needs together with sustainable and sensitive agricultural practices (Nahum and Donat, 2016).

Definition of organic and organomineral fertilisers

Organomineral fertilisers are composed of basic plant nutrients (N, P, K) with the addition of organic matter, trace elements (Zn etc.), sulphur etc. which are beneficial for both plant and soil. This type of fertilisers are produced as solid and liquid. Humic and fulvic acids in organic matter in these fertilisers are very useful for plants and soil. Sulphur substance contributes to good soil cultivation and aeration (Agrotime, 2023).

The source of organic matter in these fertilisers is obtained from agricultural, municipal, domestic wastes and animal manure, as well as from substances such as leonardite from the soil.

Leonardite organic matter

Leonardite forms from lignite oxidation during coalification and contains organic humic acids of high economic worth, ranging from 35-85% dependent on its quality (Figure 1). Leonardite also contains carbon, macro-micro nutrients (Engin and Cöcen, 2012; Wikipedia, 2023). The moisture content varies between 25% and 40% and the PH value between 3 and 5. Its quality is classified as low (35%), medium (50%) and high (65%) according to the amount of organic matter. It contains more organic matter compared to other organic matter derived from compost. In our country, it is mainly extracted from Uşak/Ilyaslı, Manisa/Soma, Denizli/Kale, Thrace/Meric etc. districts (Engin and Cöcen, 2012).

Figure 1. Leonardite (Wikipedia, 2023)

Apart from agriculture, leonardite, which is used in many industries such as animal husbandry, cosmetics, pharmaceutical industry, etc., is a good soil conditioner and conditioner. In recent years, 1.8 million tonnes of leonardite reserves have been found in Elbistan district of Kahramanmaraş, which will meet the world need. If it is brought into the economy, it is expected to save 500 million TL, especially in the field of agriculture (Haberturk, 2022).

Leonardite organic matter fertilisers are better than compost and manure fertilisers with their slow release to the soil and permanence (Engin and Cöcen, 2012; Agrotime 2023). Fertilisers obtained from municipal and domestic wastes cause significant disturbances to the environment, especially odour (Şengüler, 2015; Richentek, 2017). As a result, according to the above-mentioned, the widespread use of leonardite organic matter fertilisers in the coming years seems to be more open.

Solid granular organic/organomineral fertiliser production process

Solid granular organic/organomineral fertiliser production processes, which are more commonly produced in small and medium-sized fertiliser production plants in our country and in the world, are based on the chemical fertiliser production process. Organic fertilisers are compost type and there are some differences in the production processes of these plants compared to organomineral fertilisers with leonardite organic matter (Korkmaz, 2022). Organic compost and organomineral fertilisers are more commonly produced and used on the basis of N, P, K. Since the organic matter of compost fertilisers is obtained from wastes, it is expected to subject to fermentation and release the organic matter before entering the production process (Richentek, 2017). For this purpose, organic copmost is laid in a large area and regularly mixed and kept waiting. After that, it is put into the process. Organic and organomineral fertilisers are mixed fertilisers consisting of more components according to the needs of the plant and soil compared to chemical fertilisers. Since these components are chemically related to each other, they must be thoroughly crushed before dosing and thoroughly mixed during dosing. Otherwise, agglomeration and adhesion are commonly seen as an important problem in this type of fertilisers (Agrotime, 2023). In figure 2 shows a general solid granular organomineral/organic fertiliser production process.

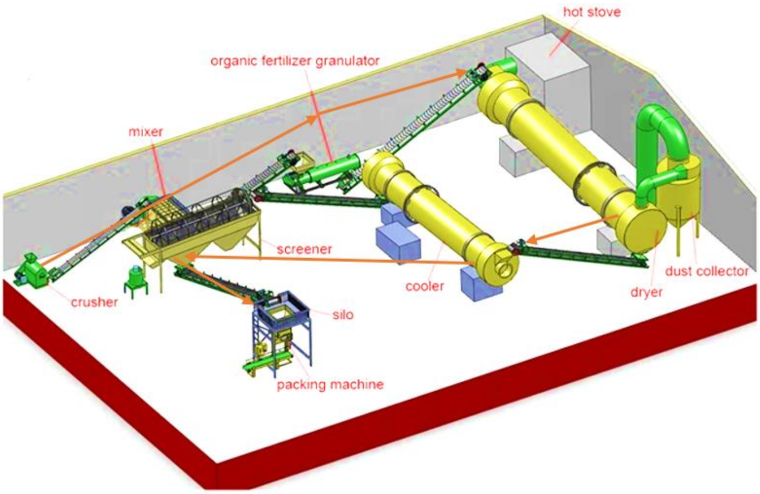


Figure 2. Organic/Organomineral fertiliser production line (Richentek, 2017, Zhengzhou, 2017)

As can be seen in Figure 2, the production process consists of crushing, dosing and mixing of fertiliser components, moistening and granulating (granulator), drying the moisture in the granules (rotary dryer), cooling the heated fertilisers to remove heat and moisture (rotary cooler), sieving granule sizes between 2-5 mm and packaging (Zhengzhou, 2017; Feeco, 2023). In some processes, granulating discs are also used in the granulation process (Agrotime, 2023).

Organomineral fertilliser rotary drum drying

Besides drying fertilizers, drying drums are widely used in industries such as food, construction, mining, pharmaceuticals, forestry, etc. (Abbasfard et al., 2013). The most important part of this production process that affects fertilizer quality is the fertilizer drying drums (Figure 3) in terms of energy, labor and maintenance costs. Fertilizer drying drums are heating cylinders that rotate around their own axis at certain rotations (1-20 rpm) with a slight inclination with the horizontal (1-7˚) (Lisboa et al., 2007; Mujumdar, 2014; Korkmaz et al., 2017).

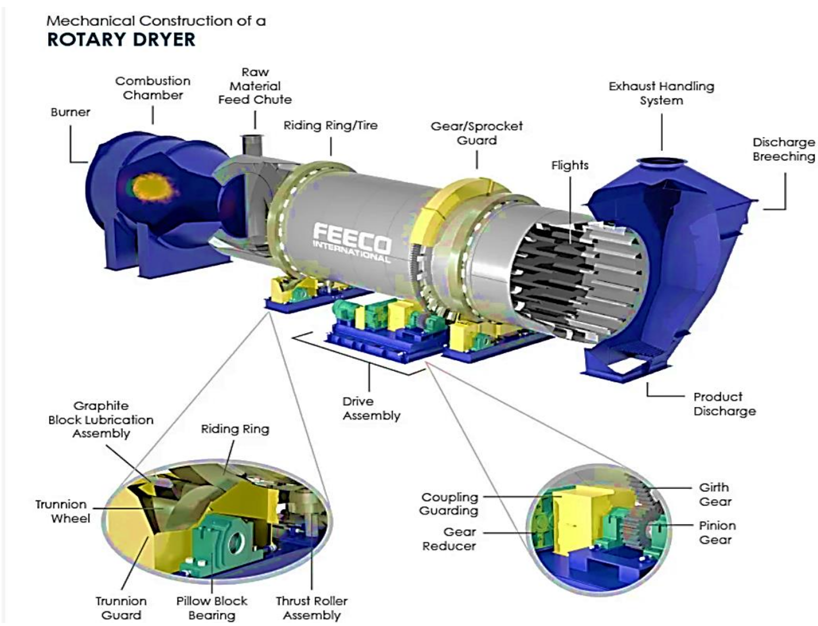


Figure 3. Organic/Organomineral fertiliser rotary drum dryer (Feeco, 2023)

In the drying drums, the flow of solid granules to be dried is in the same or opposite direction with the heated gas (air etc.) (Figure 4).

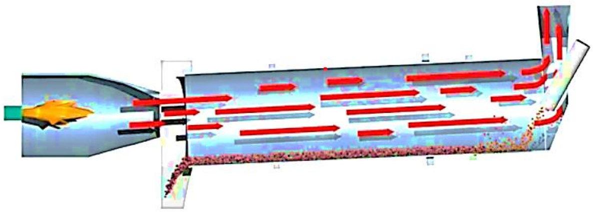


Figure 4. Counter-current fertilizer drying drum (Capitaine, 2017; Feeco, 2023)

Granules with high moisture content flow in the opposite direction to the gas, while granules with low moisture content flow in the same direction. In the opposite directional flow, the residence time of the granules in the drum is longer. Therefore, more moisture is removed from the granule pile than in the same directional flow. For granule piles with high moisture content, such as fertilizers, counter flow drying drums are used (B. C. Silvério et. al., 2010). While granulated fertilizers are conveyed to the drum at the high slope, heated air is blown into the drum from the other end to remove moisture from the fertilizer. While the air is discharged from the drum where the slope is high, the heated and dehumidified fertilizer granules leave the drum from the area where the drum slope is low and the air is blown. At the entrance of the drum, there are conveyor flights, which are arranged in a row to ensure the contact of fertilizer and air throughout the drum. The piles of fertiliser pouring from the conveyor flights form a shower curtain-like shape along the drum. The optimal width of these curtains is important in determining the drum performance or drying efficiency at the time of drying. The conveying vanes at the drum inlet are placed to prevent agglomeration of the granules (Feeco, 2023; Kacar and Korkmaz, 2021; Korkmaz, 2022).

Industrial studies on fertilizer drying drum

Especially in far Asian countries (China, Thailand, etc.), organic/organic mineral fertilizers based on traditional processes are produced in small and medium-sized enterprises and these processes are sold. In our country, similar processes are also being produced in enterprises at this level. It is noteworthy that there are no Research and development and product development departments where optimum production conditions that determine fertilizer quality and operating costs are determined and operating difficulties are eliminated, production is based on observation and experience, there are no trained qualified workers, and there are few experts and engineers in the field. In the world and in our country, there are hardly any enterprises where only these types of fertilizers are produced predominantly and where optimum operating conditions based on automation are available (Figure 5).

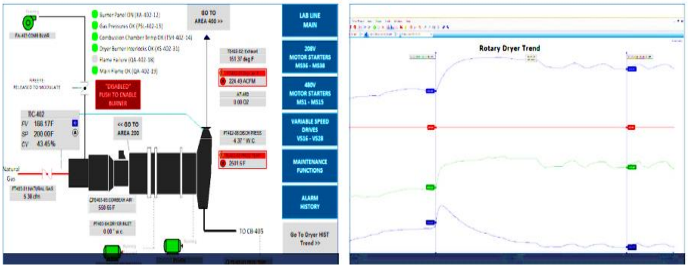


Figure 5. Automated monitoring of fertilizer drying drum operating parameters with real-time data (Feeco, 2023)

In recent years, large chemical fertilizer producers in our country have started to produce this type of fertilizers in small quantities and diversity (Feeco, 2023).

Literature studies on fertilizer drying drums

It has been stated in many studies that the optimum flights placement on the inner surface of the drum is effective in drum drying performance. These studies focus on the determination of the optimum moisture transfer of the optimum curtain width of the particle piles falling from the flights (Baker, 1988; Karali et al., 2016; Nascimento et al., 2019; Silveira et al., 2022).

There are many studies on the determination of temperature and moisture distribution along the drum. These are obtained by solving four ordinary differential equations based on the 1st law of thermodynamics (Sharples and Glikin, 1964; Thorpe, 1972; Platin et al., 1982; Kamke and Wilson,1986; Iguaz et al., 2003; Arruda, 2006; Castaño et al., 2012). The drying process is assumed to be the diffusion of moisture out of the product. This diffusion value varies according to the product. Determination of the drying kinetics or behavior of products is based on the thin film layer Lewis (2021). In determining the drying behavior of products, there are studies that use the Chilton-Colburn analogy to determine the relationship between heat and mass transfer, unlike drying kinetics that vary according to the product (Rousselet and Dhir, 2016). These studies were carried out under one-dimensional and steady-state conditions along the drum length.

These early literature studies focused on the temperature and humidity distribution along the drum length under one-dimensional and steady-state conditions. Experimental results showed acceptable agreement with model results. In these studies, it is understood that the analysis of particle dynamics, 3D and unsteady conditions, which are more relevant to real operating conditions, could not be performed due to the lack of adequate computational tools (Korkmaz, 2022).

With the development of computational tools, numerous studies have been carried out on the traceability of particle movements in the 3D flow field in the drum interior, flow regimes, and the effect of the optimum curtain flow form poured from the flights along the drum on the drum performance depending on the loading conditions. In the computational flow analyses used in these studies, Computational flow dynamics (CFD) for the flow side and Discrete element methods (DEM) for the particle side analyses were used for the interactions between the particle stacks and the fluid gas in the drum (Korkmaz and Kacar, 2021). Coupling CFD-DEM method is widely used for all kinds of interactions between the two (force, moment, heat and humidity, etc.). Although coupling analyses are important in explaining the complex physics inside the drum under real operating conditions, this analysis method has limitations in terms of computational cost (Korkmaz, 2022). On the DEM side, since each particle is calculated separately according to Newton's 2nd law of motion, significant computational difficulties arise at high particle numbers. For these analyses, computationally capable computers with multiprocessors, in some cases with multiple GPUs, are required. At particle counts of 10^8 and above, it is sometimes difficult to analyze even with these computational tools. Although the difficulties of network formation due to the complex structure of the models to be analyzed and the difficulty of the boundary conditions in the physics of the problem create difficulties in the use of this analysis model, they still provide important opportunities in the literature in analyzing the complex physics of the problem, visualizing it with moving simulations, and displaying parametric results on the model in the desired format (Kacar and Korkmaz, 2021). In order to avoid these computational difficulties and costs, important methods have been developed in the literature in recent years. Instead of traditional CFD-DEM methods, methods such as SPH-DEM, LBM-DEM, etc. have been developed that calculate each flow particle as a solid particle on the flow side as in the DEM method, and therefore do not solve the Navier Stokes equations of the flow iteratively, independent of the meshing processes that cause computational costs on the flow side (Nascimento et al., 2022). These methods continue to be developed to be successful for all flow types and for solid particles outside the cylinder and are promising for future work. In addition to the traditional CFD-DEM method of representing small particles as larger particles, the Coarse Grained CFD-DEM method is used. Much of the recent literature has focused on reducing the computational cost of the traditional CFD-DEM method of analysis.

Operational challenges encountered in the organomineral fertilizer production process

In small or medium-sized solid Organic/Organomineral fertilizer production enterprises, the traditional production process, as shown in Figure 2, has some operational difficulties that reduce fertilizer quality and create operating, maintenance, labor and time costs. Before packaging, the fertilizer granules are sieved to ensure that the size of each granule is between 2-5 mm and as spherical as possible (Korkmaz, 2022). Reducing or eliminating as much as possible the major difficulties encountered in the production process also affects the desired production quality of fertilizer.

The main problems such as agglomeration of fertilizer powder components, pile formation of fertilizer grains at the entrance of the drum during the process of loading into the drying drum, growth, breakage, dusting, sticking to the inner surface of the drum, especially due to its moist, acidic and abrasive (corrosive-abrasive) structure, disruption of the flights and drum internal structure in the drying drum and reprocessing by dusting, etc. cause significant difficulties (Figure 6) in the operation process while reducing fertilizer quality (Korkmaz, 2022). These difficulties cause significant maintenance and labor costs in the process, especially in the drying drums.

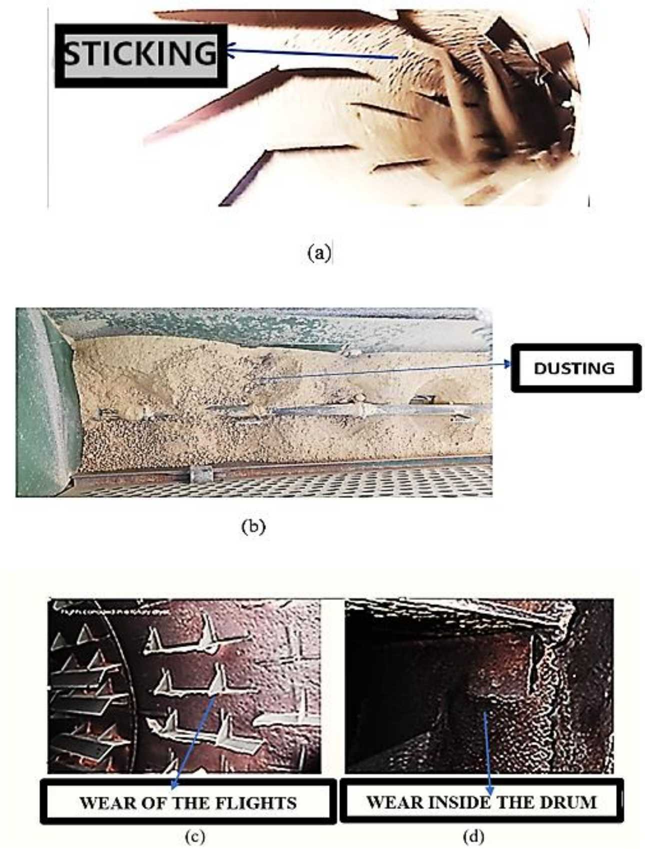


Figure 6. (a) Fertiliser dusts sticking (adhering) to the inner wall of the drum, **(b)** Dusting of fertiliser grains, **(c)** Wear of drum flights and inner surface (Korkmaz, 2022; Feeco, 2023)

Operational challenges encountered in the organomineral fertilizer production process

The agglomeration of fertilizers before the granulation process is due to the lack of crushing and mixing (Figure 2) or the absence of these processes in production.

Although the literature studies in this field are mostly focused on drying drums, there are researches on granulating drum (Rodrigues et al., 2017) and disc granulation (Lima et al., 2023).

Good sphericity values in fertiliser granules through an efficient granulation process reduce the adhesion of fertiliser granules to each other and cohesion effects with the environment. In the granulation process; the use of a granulating drum in the production of this type of fertilizers instead of a granulating disc also contributes to more granulation of fertilizer granules (Figure 7).

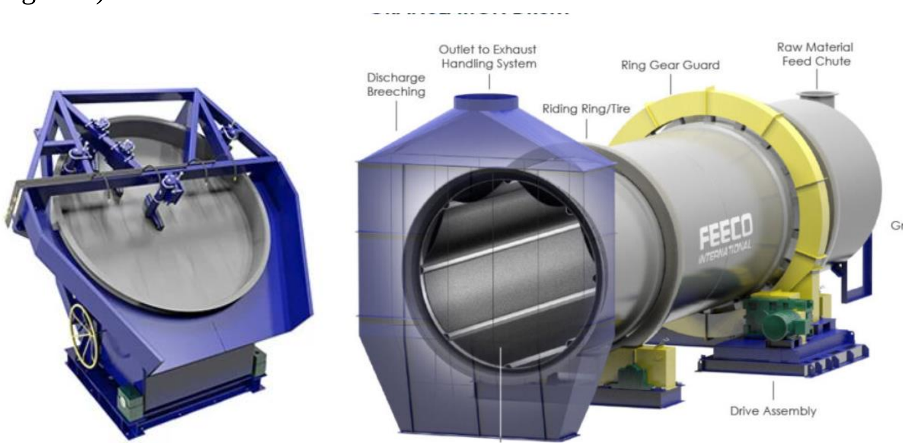


Figure 7. (a) Disk for granulation, **(b)** Granulating drum (Feeco, 2023)

In the granulating drum, there is the possibility of controlled introduction of liquefied anti-sticky powders that can prevent the granules from sticking to each other (cohesion) and their environment (adhesion). The multi-component nature of organomineral fertilizers and the high chemical affinity of the components it contains increase the tendency of these fertilizer granules to adhere to each other and to their surroundings (Cui et al., 2021; Tyc et al., 2020; Tyc et al., 2021). Depending on the type of organomineral fertilizer, depending on the moisture absorption properties of their components, the granulation process is carried out by giving the appropriate moisture in a controlled manner, providing an effective granulation process.

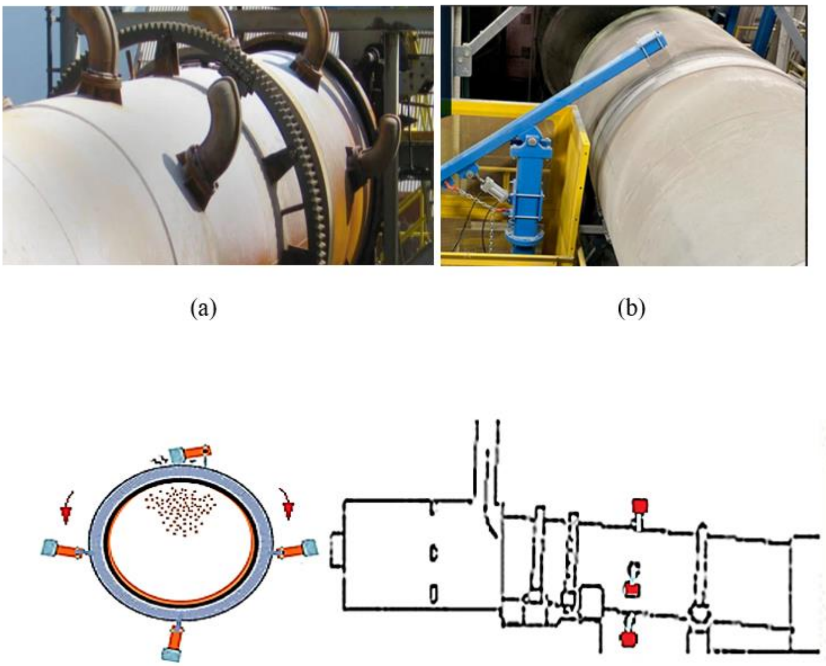
In addition, while high humidity increases agglomeration (cohesion), adhesion (Sticking to the inner surface of the drum), etc., low humidity increases the tendency of dusting. Especially the moist fertilizers coming out of the granulating disk have a tendency to form a pile at the drum inlet (Agrotime, 2023). For this reason, the placement of appropriately sloped flights at the drum inlet that convey the granule pile to the drum will prevent or reduce the tendency to agglomerate as a result of this pilling up. The fact that the drum loading parameters such as the speed of the belt used in the drum loading process, the amount of fertilizer pile carried, the angle of the pile, the pouring place where it is loaded into the drum, the angle of departure from the belt and its trajectory are compatible with the parameters that determine the drum capacity (flight; shape, profile, number, drum rotation speed, fertilizer and drying air inlet parameters to the drum, etc.) also has the effect of reducing or preventing agglomeration, growth of granule grains, etc. The design of the drum is also a factor in reducing the growth, agglomeration, dusting, etc. of the fertilizer bulk grains moving in the drum (Korkmaz, 2022). It is suitable to produce the drum with inclined flights at the entrance of the drum, a fligtless section for better granulation in the later part and then a flighted section (Figure 8).

Figure 8. Optimal drum interior design for fertiliser quality (Feeco, 2023)

The air inside the drum during drying is humid, acidic and corrosive. With the continuous movement of fertilizers granules, internal surface abrasion, various cavities, etc. distortions deteriorate the drum internal structure and flights (Figure 6c). This situation negatively affects the drum performance. These situations cause maintenance costs. The effect of wear cannot be completely eliminated, but its effect can be reduced. The choice of drum material is an important factor in the resistance of the drum to wear. Even if it is costly, making the drum material from stainless steel, special alloys (Hastelloy Inconel etc.) that best meet the challenges of the superior environment increases the life of the drum and reduces maintenance materials.

Coating materials such as epoxy-graphite etc. can be used for abrasion resistance of the inner drum wall (Korkmaz, 2022).

Periodic environmental and local or regional knocking systems outside the drum are an effective system used in the cleaning of particle dust adhered to the drum applied in the industry.



(a) (b) (c)

Figure 9. **(a)** Ball-tube knocking system, **(b)** Pneumatic hammer-knocking System, **(c)** Hammer-knocking system (Feeco, 2023)

RESULTS

In order to control the quality of organomineral fertilizer production in such small and medium-sized enterprises, to identify and eliminate operational difficulties;

- Automated adjustment and monitoring (Figure 10) of optimum production parameters according to fertilizer type (Feeco, 2023)

Figure 10. Fertiliser production system automation (Feeco, 2023)

- Implementation of efficient crushing and mixing processes
- Efficient granulation process (use of a granulating drum instead of a granulating disk)
- Determination and control of optimum loading parameters of the drum
- Establishment of optimum drying drum structure and flighting profile and arrangement suitable for organomineral fertilizer production
- Application of suitable drum material and inner lining, coating etc. for abrasion (corrosive-abrasion)
- Using chilled air instead of ambient air as the cooling air used in the cooling drum after the fertilizer drying drum
- Dehumidification of the humid air sent to the drum can increase the drying efficiency of the air (Korkmaz, 2022)
- The use and development of CFD-DEM analyses, especially in determining optimum drying or operating parameters and identifying problems in production (Kacar and Korkmaz, 2021)
- Employment of specialized personnel (engineers, technical staff and experienced workers, etc.)
- Establishment of research and development and production development departments

A Case Study

Revisions to an organomineral fertilizer production process improved the quality of fertilizer production. In this process a crushing process was added. In the granulating process, the granulating disc was replaced by a granulating drum. Appropriate granulating humidity is controlled according to the fertilizer type. Improvement was achieved in the granulating process. After the drying drum, the cooling process of the fertilizer was carried out at the cooling drum inlet. In this way, the moisture in the fertilizer was removed more effectively and hardening was ensured. Dusting (Korkmaz, 2022) occurring in the sieving process was eliminated. The hardening of these fertilizer granules reduced the holding time required for packaging (Agrotime, 2023).

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CHAPTER XI

EFFECTS OF DEFLECTOR DESIGN ON ORCHARD SPRAYERS

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INTRODUCTION

Since correct agricultural techniques at each stage of agricultural production (planting, fertilization, pesticide application, harvest and post-harvest, etc.) can affect product yield, machines aiming for high product efficiency are preferred for each stage. Looking at the agricultural machinery sector, manufacturers often design high-tech machinery focused on doing the targeted job rather than optimizing energy consumption for these sensitive stages of agricultural production. In other words, they often ignore developing machines to do more work with less energy (Failla et al., 2020).

Especially among plant protection machines, the sprayers that require the most power and therefore fuel consumption are airblast sprayers. In this type of sprayers, when calculating the power requirement; (1) the draft power required for the sprayer, (2) the power requirement for pressurizing the agricultural pesticide by the pump and mixing the pesticide in the tank, and (3) the power required for the operation of the airflow unit (Turbo unit) is taken into account. However, due to the highest power requirement, fuel consumption is spent in the operation of the airflow generating unit. The turbo units of the orchard sprayers offered to the market in our country are produced by a few local manufacturers, mostly by copying them (mostly from machines of Italian or German origin) and offered to the domestic market. As it is known, in the world where the importance of energy increases day by day, it is becoming increasingly important to carry out every process with high energy efficiency. Otherwise, the farmer will spend a lot of energy to obtain the agricultural product, as a result, the cost of the agricultural product will increase and the profitability of the product will decrease. Reverse Engineering and R&D (Research and Development) are required to produce machines that both perform their functions precisely and provide high energy efficiency.

When the general profile of most manufacturers in our country is examined, it is seen that they manufacture an exact copy of any machine manufactured abroad and do not know the know-how in detail. Although the most companies manufacturing Agricultural Machinery do not have R&D departments, many of the businesses that have R&D departments do not fully carry out R&D. In the R&D departments of businesses, designing a unit from scratch, evaluating it in terms of high energy efficiency, redesigning its functionality, reducing the number of assembly elements, using a different material, ensuring easy manufacturability, increasing its functionality by simulating it in 3D software programs, reducing manufacturing-assembly costs, etc. studies are not carried out. The similar product brought abroad is disassembled and geometrically similar is made; steel class, heat treatment, manufacturing method, finding the main purpose and root cause analysis, etc. features are not examined.

Comparison of Turbo Fan Units in View of Energy Consumption

One of the important stages of agricultural production is the pesticide application to pests. The purpose is to carry out the most efficient pest management through the least spraying for a successful pest, disease and weed control (Toraman, et. al., .2021).

While the spraying machines are designed for a specific fruit tree, there are also sprayers that can be used for general purposes (suitable for use on all fruit trees). The main machines used for horticulture are orchard sprayers (turbo atomizers), which are produced for general purposes (low application volumes and applications targeting the outer part of the tree canopy) (Bayat et al., 2006). The reason why these machines are preferred is that they have the potential to carry the sprayed droplets to the upper parts of the tree canopydr and the inner parts of the canopy with the air flow. However, a good pesticide coating, distribution and low pesticide drift potential on the target surfaces in the outer and inner parts of the tree canopy vary depending on the air jet profile and airflow velocity and flow rate of the turbo unit on the machine (Salyani and Farooq, 2003). Duga et al. (2015) measured the air speeds of orchard sprayers with different designs with a three-dimensional hot wire anemometer and determined the air jet in the flow analysis program according to the measured regions (Figure 1). According to this study, although the Airblast Sprayers are highly preferred, it has been revealed that the air jet is more unstable than other designs. In addition, it is seen that in trees with high canopy height, the droplets cannot reach the top areas of the tree canopy with the air flow. In such studies, trials are generally carried out according to the ISO 9898 standard (Bayat et. al., 2017).

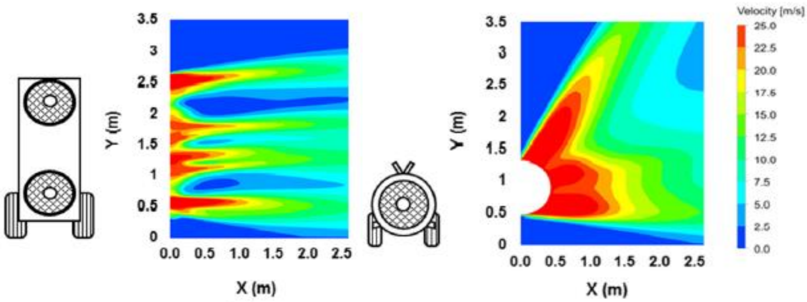

Figure 1. Comparison of air velocities of tower double fan and standard type single fan airblast sprayers depending on tree canopy and distance from the machine (Duga et al., 2015)

Endalew et al. (2009) compared the air jets created by orchard sprayer and two different tower type orchard sprayers in their study. Considering that the air jet has components in three different axes (velocity components in the x, y, z axes, respectively, u, w, z), it is important that all the kinetic energy of the air leaves the jet without being distorted in a single axis as much as possible. Accordingly, it has been observed that the orchard sprayer creates air jets in other axes (y and z axes) besides the horizontal axis (y) (Figure 2). However, this situation; The air jet of the 4-fan orchard sprayer with tower was not formed in the x and z axes, the kinetic energy of the air jets could be transferred directly to the y axis, and the amount of energy converted into productive work increased. It is important that it can transfer the air speed homogeneously to a single axis and leave the fan outlet without turbulence. When more than one fan overlaps, the air jet components formed in other axes may lose their effects. In spraying with orchard sprayers; even if the pesticide is distributed partially homogeneously on the target surfaces, there may not be sufficient coverage on the upper crown of the tree. The reason for this situation is that the air speed that carries the droplets to the tree canopy is insufficient. However, if the air outlet units of the orchard sprayers are improved, the air speed produced can increase, the kinetic energy given to the air will be converted into more work and the efficiency of the fan will increase.

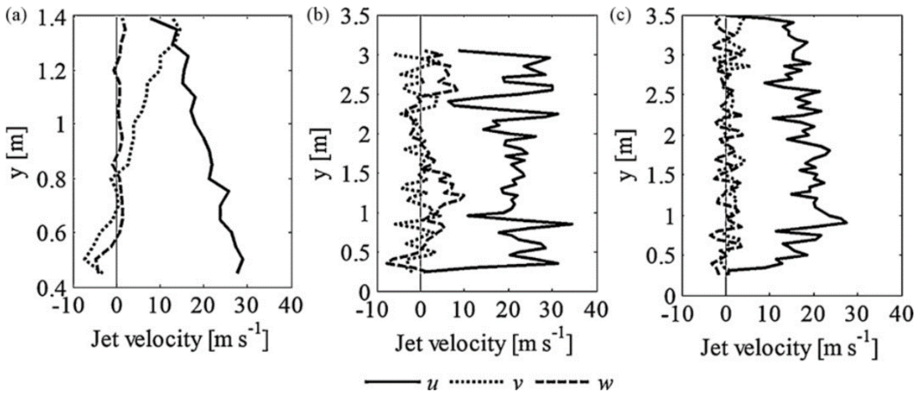

Figure 2. Velocity components of the standard type single-fan orchard sprayer **(a)**, the towered double-fan **(b)** and the towered 4-fan orchard sprayer **(c)** in other axes (x,y,z) depending on the distance from the machine (u,v,w) comparison (Endalew et al, 2009)

Energy Efficiency and Coverage

The studies are being carried out on what the sufficient air velocity should be for a good coverage on the leaf surface. Tsatsarelis (1979) determined the maximum air speed at the exit of smooth-leaved trees as 3 m/s. Balsari et al. (2008) stated in their study that for a good leaf surface coverage, the air speed at the exit of the tree crown should be 5 m/s. However, another method applied by most farmers is that the physical indicator for the most suitable air capacity and carrier air speed in applications with orchard sprayers is that the angle between the leaves on the outer part of the crown relative to the machine and the ground plane is between 25º and 45º. While the leaves are moving within this position area, air flow is considered sufficient. In this way, the upper and lower surfaces of the leaves exposed to turbulence are provided with a better coating. However, since there is insufficient air, the leaves on the outer part of the canopy relative to the sprayer may remain motionless.

Even with the high air capacity fans used in orchard sprayer (high capacity axial fans with a diameter of 900 mm and 1000 mm), sufficient air flow may often not reach the inner canopy and top of mature citrus trees. However, it is possible to increase the air flow rate produced by consuming the same amount of energy in the orchard sprayer. With various engineering approaches in the turbo unit of airblast sprayers, the energy of the air flow created by the fan can be directed to the target with less friction losses. Some approaches to consider for this are; optimization of the number of fan blades can be in the form of changing the fan blade material, changing the fan blade angle, changing the tolerance of the fan guard relative to the fan blade, reducing the units that disrupt the flow of airflow, and design studies that ensure the airflow passes through the fan guard with less loss (Itmeç and Bayat, 2021).

Principle of the Turbo Fan

The fan of orchard sprayer is manufactured as axial type. In this type of fans, the kinetic energy of the air entering the fan housing increases thanks to the rotating fan blades and the air moves forward without changing its axis. However, since the spray nozzles are aligned with the circular structure of the fan housing, it is necessary to direct this air flow to the nozzles. In Orchard Sprayer, a pump is operated by the drive taken from the tail shaft, and the pump sends the pesticide, it takes from the tank to the spray nozzles with the desired pressure. However, since the kinetic energy provided to the droplets by the pump is not sufficient, an additional driving force is needed for the droplets to reach the leaves on the tree. For this reason, the air flow provided by an axial fan driven by the tail shaft hits the air reflecting unit (deflector) and its 90º direction changes, and in this way the air flow is directed to the spray nozzles (Figure 3). The droplets, which initially have low momentum, take the air flow behind them and their momentum increases thanks to the air flow. The droplets coming out of the nozzles can reach the tree canopy by taking the air flow from the air reflector behind. As the air flow carrying the droplets coming out of the nozzle leaves the fan, Its kinetic energy may decrease in the free atmosphere (Larbi and Salyani, 2012b), and within the tree, its kinetic energy decreases due to the resistance of leaves and branches to the air flow (Frisio et al., 2015). If the air flow passes through an area that can reduce its kinetic energy less after leaving the fan, the kinetic energy of the air flow will decrease less. Thus, by improving these areas, the air flow will travel further despite the speed losses due to the pressure in the free atmosphere and within the tree.

In the basic working principle of axial fans, the air sucked into the fan leaves the fan on the same axis. However, since the nozzles are arranged around the fan of the orchard sprayer, it is necessary to direct the air with increased kinetic energy in the axial fan of the orchard sprayer to these nozzles. In this way, the droplets coming out of the nozzles can reach the tree canopy more easily thanks to the air flow behind them. The air deflector element used to direct the air flow to the nozzles must be able to reduce the kinetic energy of the air flow produced as little as possible and turn the direction of the air flow 90° towards the nozzles. That's why the design of the air deflector; The conicity peak angle, height, cone base diameter and the material of the air reflector are very important.

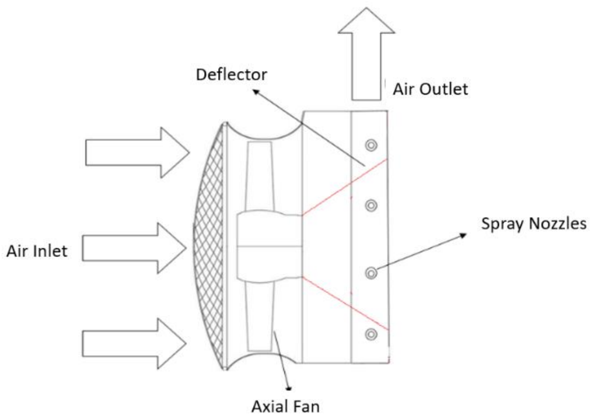

Figure 3. An image showing the working principle of the fan of the orchard sprayer

Types of Deflectors

In face-to-face interviews with manufacturers, it was stated that air deflector units were manufactured without any engineering calculations. There is no production-based standard, material type, geometric shape based on engineering calculations, etc. for these sections. Air deflectors for fans of different brands are produced in different geometric sizes and different geometric ratios. Air deflective element of the orchard sprayer; it can be produced as one-piece hard plastic combined with a body (Figure 4a), one-piece steel (Figure 4b), one-piece flow flow guide (Figure 4c), and two-piece steel (Figure 4d). For this reason, the air flow produced by two orchard sprayers with the same fan diameter may be different at the same fan speed, even if the number and size of the fan blades are the same. In fact, the materials of these air deflector units are made of hard plastic as well as steel. Since these units do not have any standards, a significant part of the kinetic energy of the air flow coming out of the fan can be spent in these sections when changing the direction of the air. Therefore, before manufacturing, the air reflector designed in the computational fluid dynamics (CFD) program should be subjected to preliminary evaluation, its air efficiency should be determined and then it should be manufactured.

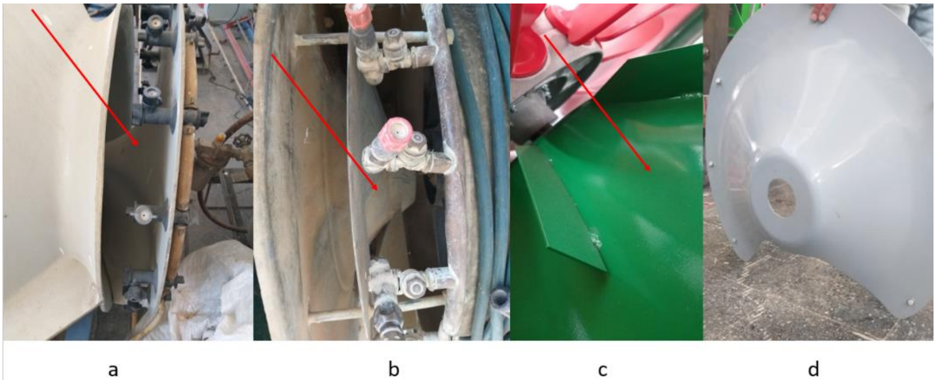

Figure 4. Air reflective designs produced by different companies are made of hard plastic combined with a one-piece body (Figure 4a), one-piece steel (Figure 4b), one-piece steel with flow guide (Figure 4c), two-piece steel (Figure 4d)

In field studies, visits to orchard sprayer manufacturers, conferences and workshops, and interviews with manufacturers and farmers, it was stated that the equipment that consumes the most power in citrus agriculture is the orchard sprayer. The majority of domestic manufacturers who manufacture orchard sprayers with axial fans purchase ready-made parts and assemble them, and often do not even make engineering calculations. Although the fuel consumption is high in these machines, which consume a lot of power and can even overheat the tractor at times, the air flow rate produced may still not be sufficient. For the energy efficiency of this machine, it is necessary to increase the energy efficiency of the unit that produces the air flow (fan and air reflector unit). When we look at the overall studies carried out for energy efficiency; Studies are carried out such as optimizing the number of fan blades (5-12 pieces), reducing the gap between the rotor and the body, changing the maximum location of the blade shape, preventing corrosion on the blade surface, and removing obstacles at the fan outlet (Izadi and Falahat, 2008). In fact, recent studies have shown that there are systems that instantly change the angle of the wings and the air outlet opening via remote connection (Salcedo et al., 2021).

Recent Studies

When the literature is examined, it is seen that systems and machines have been designed to administer the pesticide more efficiently and effectively. When the studies carried out in this field are examined, studies such as adjusting the jet profile created by the orchard sprayer according to the tree crown, using the energy spent on the pump and fan more efficiently, providing the right amount of pesticide-air flow mixture, and examining the effectiveness of a designed machine with fluorometric methods are mostly included.

Pai et al. (2009) redesigned the air outlet unit of a orchard sprayer with axial fan in their study. Thanks to the air directing element placed in the unit they designed, the air coming from the axial fan can be directed to the nozzles (Figure 5). With the help of a laser sensor, the crown geometry of the aerial tree is read instantly. By changing the position of the air reflector with the data received, the amount of air flow sent to the tree is changed. Accordingly, the volumetric air flow rate provided can be changed between 7.6 and 1.9 m^3/h. In this way, drift was reduced by 37%.

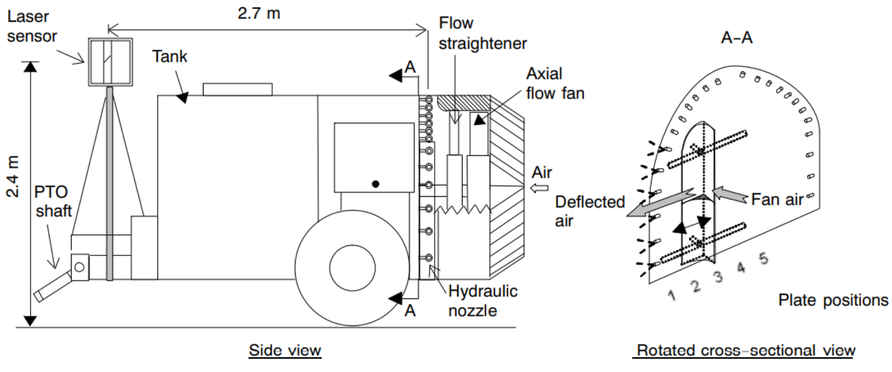

Figure 5. Visual of the system that can instantly change the position of the deflector (Pai et al., 2009)

Khot et al. (2012) designed a system in which the fan outlet can be adjusted in the part where the air flow is directed to the nozzles in orchard sprayer with an axial fan (Figure 6). As the air velocity increases when the opening decreases, the droplets reach the trees with higher canopy height more easily. While examining the effectiveness of the orchard sprayer, the spraying effectiveness and air flow rate on the trees corresponding to the left side were measured when viewed from the rear of the tractor. In static and dynamic studies, it was revealed that the air flow was used 70% more efficiently and the pesticides used were used 50% less.

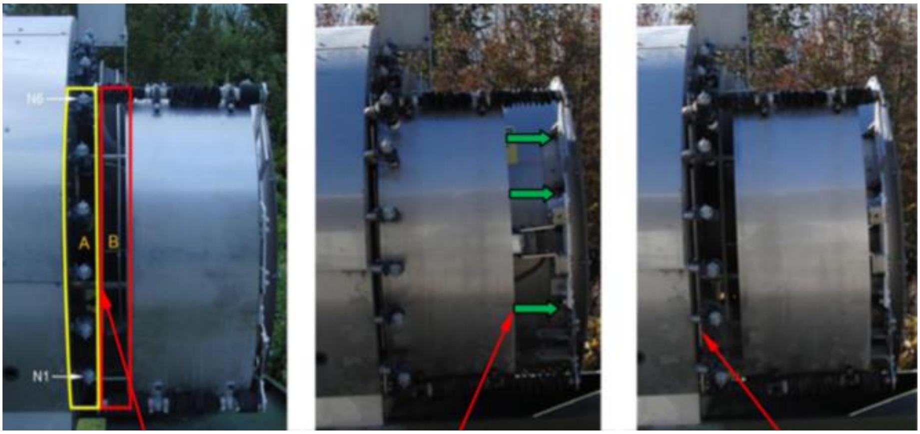

Figure 6. Designed system that instantly adjusts the opening of the fan outlet (Khot et al., 2012)

When the systems with changed airflow are examined above, it is seen that the air outlet opening has been changed. In this case, it is clearly understood that turbulence may occur in the area where the nozzles are located and the mechanical efficiency of the process is quite low. Because the fan rotates at high speed and the mouth on the outlet side of the air is narrowed, causing the air coming out of the fan to come out with difficulty. Salyani and Farooq (2003) revealed in their study that when they increased the air outlet opening in the nozzle area from 40 mm to 100 mm, the total energy consumption decreased by 69%.

In his study, Çelen (2008) designed an additional deflector on the orchard sprayer. This orchard sprayer with a deflector was tested at different reflector angles of 0º, 20º and 40º in an orchard with apple trees with a crown height of 1.8 m in the Marmara Region. In the experiments, it was seen that better coating was obtained on the leaves of apple trees in applications made with a 20º reflective angle, the reason for this is that the canopy height of apple trees is low. The study concluded that a higher reflector angle is required for apple trees with higher crown width. In addition, according to the results obtained from filter papers whose spraying effectiveness was examined with water-sensitive fluorometric methods, it was determined that drift decreased by 25.7% thanks to the reflector.

The spraying efficacy of several spraying machine types was studied in a vineyard by Pergher et al. (1997). They claimed that they might have gotten a superior leaf coverage of about 12% if the fan air inlet had been angled at 118º degrees as opposed to 90º degrees (Figure 7). It has been discovered that drift losses in vineyard treatments using a traditional axial fan garden sprayer can range from 46% to 69%, depending on the different vegetative stages. Additionally, drift has decreased by adjusting the double-fan garden sprayers' air output locations to 30º or 45º degrees.

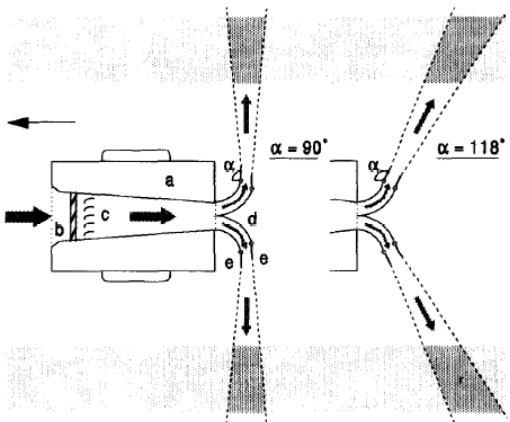

Figure 7. Visual of their design (Pergher et al., 1997)

In their study, Pezzi and Rondelli (2000) tested a orchard sprayer whose air outlet angle could be 90º and 120º degrees in a vineyard. In the experiments where the fan speed was selected as 1400, 2000 and 2500 min^{-1}, it was determined that a better coverage was achieved and the distribution uniformity became better at medium and low fan speeds when the air outlet opening was 120º. It has been stated that if the fan speed is 2500 min^{-1}, the drift can increase up to two.

In his study, Pekitkan (2015) aimed to better direct the air jet created by the fan to the tree with the tower type air direction unit they designed for the air outlet areas of the orchard sprayer with axial fan. Thanks to the laser sensor they used, the tree crown was scanned and the amount of medicine was excreted more efficiently according to this canopy. Thanks to water-sensitive papers and filter papers, the results of image processing and fluorometric methods were evaluated and the results were compared. 50% less pesticide was used compared to comparisons with traditional machines.

In their study, Sever and Özarslan (2015) designed an air direction element for orchard sprayer and conducted a study on determining the performance of this design. In the spraying processes using trace material, the coating methods on the vine plant were carried out with image processing methods and the fluorometric method was also tried and the results of the two methods were compared. When the design was compared with the traditional machine, it was stated that the coating rate increased by 40%.

When the studies summarized above are examined, it becomes clear that the air deflectors in the fan are not evaluated in terms of energy efficiency. There are designs in the works that increase the effectiveness of spraying and aim to ensure that the droplet meets the tree canopy better.

Comparison of the Conical Peak Angle

There are many studies on the impact of an air jet on a conical surface. The essence of these studies is to study the effects of the taper top angle obtained by changing the taper ratio L/H (the ratio of the taper radius to its height) (Abdel-Fattah et al., 2014). In their study, Liu et al. (2011) compared the apex angles of 30º, 45º and 60º when changing the direction of the oncoming air jet, and stated that the air speed decreases at a peak angle of at least 30º taper. Tang et al. (2017) emphasized that the decrease in jet speed is minimal when the taper peak angle is 15º. They stated that vortices formed on the surface where the jet hit, especially when the taper angle was 70º, and these vortices experienced a decrease in kinetic energy (Figure 8).

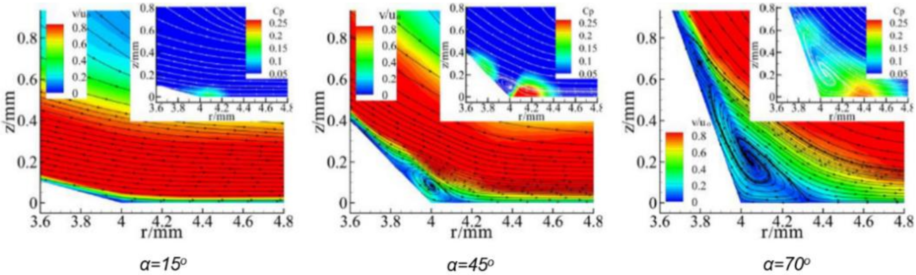

Figure 8. Comparison of jet speeds with the taper peak angle (α) (Tang et al., 2017)

The peak conicity angle of the air reflectors of existing domestically produced turbo atomizers varies between 15º and 25º. In most orchard sprayers, the air flow is directed only at an angle, it hits the surface and is then directed to the nozzles. However, if the air deflector is designed at the right angle, it will direct the air coming from the fan towards the nozzles with minimal energy loss. In this way, the incoming air flow can be directed to the nozzles by creating a small reaction force on the air deflector. It is possible to find the reaction force with the following formulas (Çengel and Cimbala, 2004):

$$\sum F = \sum \beta m V_{out} - \sum \beta m V_{in} \quad (1)$$

Here, F is the air reaction force on the air deflector (N), β is the momentum correction coefficient (1.1), m is the mass flow rate, and V_{out} and V_{in} are the air velocities leaving and entering the reflector. Since it is known that reaction forces will only occur horizontally (x-axis), the formula simply becomes the following:

$$F_{Rx} = mV_{out}cos\alpha - mV_{in} \quad (2)$$

Here, assuming the velocity of the air entering the fan is constant, it is important to determine the correct angle, as the reaction force will decrease with the decrease of the conicity angle α of the air reflective element shown in Figure 9). Also, when calculating power;

$$P = FxV \quad (3)$$

formula is used. Considering that F_R is the force (N) and V (m/s) is the speed of the incoming air flow, it can be calculated how much energy the air deflector absorbs in the system.

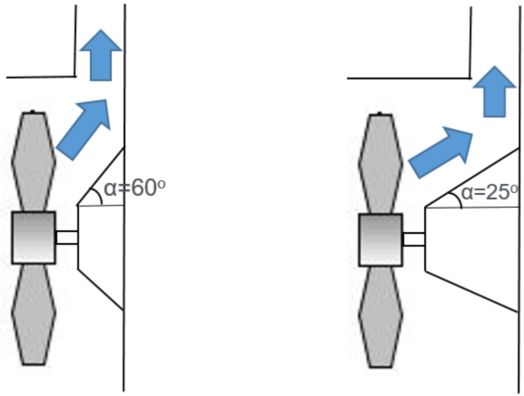

Figure 9. Decrease in the peak taper angle (α) of the air reflector

It is noteworthy that there is no standard for the deflectors used in orchard sprayers and there is not enough work on increasing the efficiency of these machines. Although there are many studies on pesticide application efficiency, it is also important to evaluate these machines in terms of energy efficiency. If the energy efficiency of the turbo unit of these sprayers is made higher, the amount of energy currently consumed will decrease and the air flow they produce with the same amount of energy will increase, so droplets will be able to reach the upper part of the tree crown. When more airflow is created in the fan by consuming the same amount of energy, the mechanical efficiency of the fan will increase. In this way, more work will be done with unit energy.

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CHAPTER XII

ROBOTIC PLATFORMS IN AGRICULTURE

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INTRODUCTION

Throughout history, the human race has turned to simple tools and mechanisms that make their work easier. In this way, they aimed to do their job with less effort. However, with the advancement of technology, the need for manpower for today's work has begun to decrease. With industrialization, technologies brought by the internet and satellite technologies, the robot age offers different opportunities day by day.

Robots are any autonomously run machines that eliminate the need for human labor, even if they may not look like humans or carry out tasks in a way that is humanlike. By extension, robotics is the engineering discipline dealing with the design, construction, and operation of robots. Day by day, it is widely used in the manufacturing industry, surgical interventions, ports, space etc. and especially in agriculture. Also in the near future, human-looking robots will even be in our homes.

Farming and agricultural robots have reached a completely new level as a result of developments in simulation platforms and virtual control environments, as well as the accessibility of reasonably priced computers with powerful processors and graphics cards and the expansion of open-source programming communities. The development of agricultural robots has been driven by the integration of digital tools, sensors, and control technologies, exhibiting enormous potentials and advantages in contemporary farming. These developments include anything from digitalizing fields and plants by swiftly gathering precise temporal and geographical data to completing challenging nonlinear control tasks for robot navigation (Shamshiri et al., 2018).

Most of studies stated (Liu et al., 2021; Dayıoğlu and Türker, 2021) the technological developments in agriculture are divided into 4 long-term and named the transformation from Agriculture 1.0 to Agriculture 4.0 (Figure 1). The uniform application of water, fertilizer, and pesticides over entire fields will no longer be essential to Agriculture 4.0. Farmers will instead employ the very minimal quantities necessary and concentrate on a small area. Aerial photographs, GPS technology, temperature and moisture sensors, and robotics will all be used in agriculture in the future. Farms will be able to be more productive, efficient, safe, and environmentally friendly thanks to these cutting-edge equipment, robotic systems, and precision agriculture techniques. Therefore Robots, especially in the field of agriculture, will become relatively more important. The reason is very difficult for robots working in open areas to detect and respond to biological material of variable sizes according to topographical features that can change at any time.

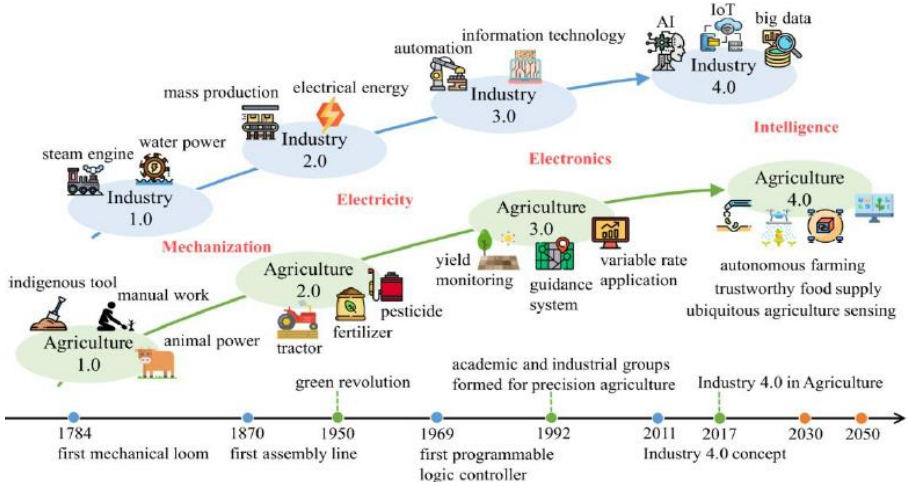

Figure 1. Time lines of industrial revolutions and agricultural revolutions (Dayıoğlu and Türker, 2021)

According to Bechar and Vignault (2016), The usage of robotics in agriculture has to comply with the following rules:

- The capricious requirements for manipulating specific produce must be considered first.
- The agricultural task and its components must be feasible using the existing technology and the required complexity.
- The cost of the agricultural robotics alternative must be lower than the expected revenue. However, it do not have to be the most profitable alternative.

In most cases, the implementation of robotics technology in agriculture is realisable if at least one of the following conditions is met:

- ✓ The cost of utilising robots is lower than the cost of any concurrent methods.
- ✓ The use of robots enables increasing farm production capability, produce, profit and survivability under competitive market conditions.
- ✓ The use of robots improves the quality and uniformity of the produce.
- ✓ The use of robots minimises the uncertainty and variance in growing and production processes.

- ✓ The use of robots enables the farmer to make decisions and act at higher resolution and/or increase the producequality in comparison to the concurrent system to achieve optimisation in the growing and production stages.
- ✓ The robot is able to perform specific tasks that are defined as hazardous or that cannot be performed manually.

Robot types mostly used in Agriculture

Flying (drones), wheeled (single to six wheels and tracked robots) and fixed type robots are especially preferred in the field of agriculture. A stationary robot, also known as a robot that is affixed to a surface like a floor, ceiling, or walls, is the most prevalent kind of industrial robot. The International Federations of Robots (IFR) lists SCARA, Articulated, Cartesian, Delta, and Polar as the top five categories of stationary industrial robots. The features of these are presented in Table 1.

Table 1. Stationary Types of Industrial Robots according to IFR (Anonymous, 2023)

	SCARA	Articulated	Cartesian	Delta	Polar
Advantages	Accurate	Flexibility	Cost effective	Quick motions	Simple control systems
Disadvantages	Less efficient	Cost	Only in x,y,z axes	Motion restrictions	Fast operations

At the latest point in precision agriculture, systems that perceive, decide and respond have become widespread. The robotics are widely used in agricultural stages as soil tillage, planting, fertilization, spraying, hoeing, irrigation, pruning, mowing, harvest and post-harvest operations. Based on the study by Blackmore et al. (2007), agricultural jobs are divided into five main operations for open arable farming. Figure 2 depicts the five major operations. Depending on the crop and the country's agricultural style, some of the suboperations represented as being a part of the major operations may be ignored.

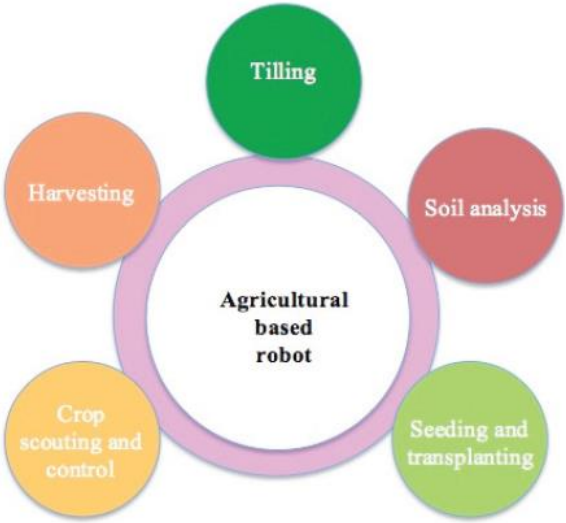

Figure 2. Task-based agricultural robots (Blackmore et al., 2007)

Robots for Tillage

The initial phase in farming is called tilling, and it entails working with the soil to prepare the ground for planting by loosening soil particles, mixing nutrients, and mixing dirt above and below the surface. By eliminating weeds and insect pests, tilling also helps crops flourish (Kladivko, 2001).

Matsuo et al. (2002), created a tillage robot that can both do an unmanned tilling and a manual operation while being able to recognize its own position and heading in the field. The tilling robot was made up of the robotized vehicle "ROBOTRA" based on a commercial tractor, the navigation system "XNAV" based on a surveying system, and the control system made up of a factory computer from a commercial business and the original vehicle controller. The robot's fundamental operating system was created to carry out a tilling activity in a traditional manner. By changing the fundamental operation software, operation software for carrying out various agricultural tasks, such as sowing and soil paddling, was also created (Figure 3). According to the results of experiments on unmanned operation, the work efficiency was nearly on par with that of traditional manual operation. The robot outperformed a trained operator in terms of the correctness of the work in the returning operation.

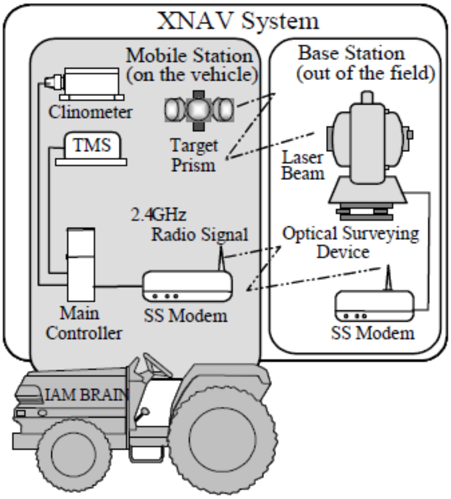

Figure 3. Designed tillage robot (Matsuo et al., 2002)

In order to assure that software systems and manufactured robots will adapt, Panarin (2021) built existing software for tilling robots. Additionally, by utilizing ROS (Robot Operating System) and modifying digital robots to their environment, client requirements have been completely met. Additionally, the ROS (Robot Operating System) and environmental adaptation of digital robots have completely met client needs.

Soil Analysis with Robots

Since soil is the primary source of nutrients for plants, numerous tests are manually carried out in the field by collecting samples from various locations and then estimating the soil attributes using statistical analysis. The quantity and density of the measurement locations affect the outcomes of laboratory experiments. The method to determine various soil qualities is time- and money-consuming. An automatic soil penetrometer was created by Scholz et al. (2014) and included in the autonomous Bonirob mobile robot (Figure 4). The soil penetrometer has a probing rod with a force sensor that, with the help of a linear actuator, can reach a depth of 80 cm in the soil. This robot can measure the physical characteristics of the soil and has sensors for surface moisture and temperature.

Figure 4. Multipurpose BoniRob and different Apps. Phenotyping-App: multi-sensor App for plant characteristic measurements, Penetrometer-App: soil- properties like cone index (CI), temperature and moisturemeasurements, Precision-Spraying-App: camera-based application forselective weed control (Scholz et al., 2014)

To identify certain chemical properties of soil, Pobkrut and Kercharoen (2014) created a soilsensing survey robot based on an electronic nose. Six wheels and six gas sensors were present on the robot. The Arduino Mega 256 controller was utilized to collect sensor data and control the complete system.

The data was supplied to the system by the robot over a Zigbee-based wireless network. The robot was tested in the field with various soils, including sandy soil, sandy soil with fertilizers, loamy soil, and loamy soil with fertilizers.

Robotic Applications in Sowing and Planting

Seeding is the process of planting seeds in the soil so that they are successfully able to germinate. Transplanting involves placing a small plant seedling that has germinated in a particular position in the field based on the specific space requirements of each crop in the field. Traditionally, sowing and planting duties have been carried out by specialized planting equipment attached to the tractor. Tractors, on the other hand, are heavy machinery, and their frequent locomotion throughout the farm increases soil compaction. Soil compaction has several negative effects on agricultural environments, including increasing apparent density and soil resistance, decreasing porosity, the rate of water infiltration, and aeration, as well as affecting chemical properties and biogeochemical cycles, affecting plant development, and soil biodiversity.

Lin et al. (2015) created a 4-wheel drive/4-wheel steering robotic platform that is suitable for the working environment and agronomic needs of wheat precision seeding techniques (Figure 5). The wheels' rotation and steering are controlled individually by four servomotors for propulsion and four step motors for steering. The eight motors were controlled by a central controller. They used four identical wheel modules, each with steering and propulsion capabilities. The platform enables the vehicle to be oriented in any desired direction and to change or retain the vehicle orientation independently of the vehicle displacement direction, even during the turning operation. In varied sowing speeds, field testing revealed that qualified seeding rates exceeded 93%.

Figure 5. Wheat precision seeding robot (Lin et al., 2015)

Pest Management with Robots

Weed Detection

Following the completion of the sowing stage, the farmer must constantly monitor the planting growth to ensure that it is disease and pest free. According to FAO figures, pests and illnesses destroy 20 to 40% of global crop yield. Weed invasion severely compromises agricultural growth and can even destroy crops totally. Weeds can attract pests as well as small animals such as snakes and mice. As a result, the earlier it is extracted, the fewer the financial damages (Oliveira et al., 2021).

Weeding is one of the most time-consuming and labor-intensive agricultural jobs. Weeding is done either by spraying chemicals on the weeds and plants or by mechanically eliminating them using blades, fire, and other means. Uniform chemical weeding applications were and continue to be the most common way to combat weeds since pesticides are selective enough to only harm weeds and not the crop, even if they blanket the crop. However, due to ongoing pressure to transition toward more sustainable agriculture, spot spraying, in which only selected sections of the fields receive pesticides, and mechanical weeding, in which no chemicals are used, have gained favor in recent years (Özlüoymak, 2021; Özlüoymak, 2022).

Disease/Insect/Deficiency Detection

One of the most difficult challenges in agricultural robots is detecting anomalies in plant output. Pathogens that require completely different treatments can exhibit symptoms that are very similar; for example, yellow discoloration of the leaves can be caused by nutrient shortages, fungi, and insects. Furthermore, symptoms are not always evident because they might be found on the underside of leaves or even under the bark, making detection much more difficult. Finally, such systems must be highly accurate and sensitive in order to minimize false-negative detections, which can cause significant financial damage to the producer and be irreversible during the growing season. Because the stakes are too high, such robotic systems have failed to gain acceptance among the research community for the reasons stated above. However, due to the importance of detecting such anomalies in time, the increasing cost of Plant Protection Products (PPP), plant enemy resistance to existing chemicals, and ever-stricter regulations regarding PPP application, automation and robotization of anomaly detection will be one of the few ways to move forward (Cheng et al., 2023).

Spray Robots

Spraying is a common strategy in agriculture to combat harvest losses. The most typical spraying tasks that a farmer must undertake during a crop season to keep as much of the cultivated produce as possible are weed control, pest management, and disease prevention. Apart from plant watering, this activity is regarded the most important procedure because it boosts profit and product quality. Traditional spraying tactics have been shown to be highly damaging to the environment due to the uniform application strategy. Currently, the rate of spraying is unaffected by the presence of disease or weeds or the stage of plant growth. In essence, growers spray liberally to guarantee complete coverage. The local ecology as well as the customers who will eventually buy the goods are permanently harmed by this technique since it creates significant soil and groundwater contamination. The spraying process is also quite labor-intensive and dangerous for the operators, who must put on safety gear to avoid contamination (Fountas et al., 2022).

Spraying pesticides on fruits and vegetables, like spraying pesticides on field crops, has a negative impact on the ecosystem due to excessive spraying ranges. As a result, many pesticide spraying robots have been developed to accomplish more precise spraying through the use of various methods such as servo-controlled nozzles, flow control systems, and ultrasonic sensors. Pesticide spraying robots have received a tremendous deal of interest and research effort. Seol et al. (2022) suggested a semantic segmentation-based flow control system for a smart spraying robot (Figure 6). Following that, contrastive field experiments were done to show that the suggested system outperformed existing control systems.

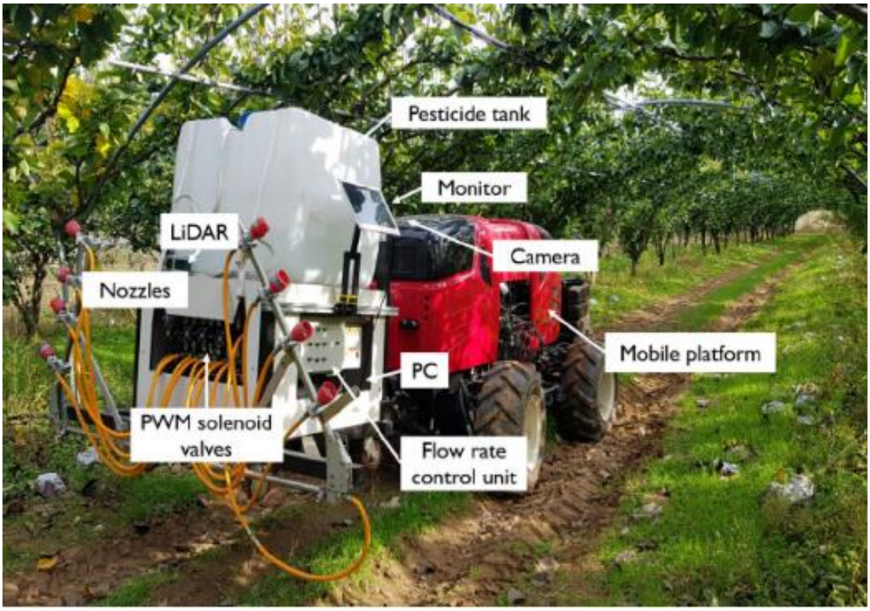

Figure 6. Intelligent spraying system (Seol et al., 2022)

Beside weed, disease detection robots are also used for drift reduction in pesticide applications. Pesticide spray drift, defined as pesticide movement by wind to any point other than the intended region, is dangerous to human, animal, food safety, and environmental health. Spray drift cannot be totally eliminated when spraying with field crop sprayers, however it can be decreased by developing different technologies (Soysal and Bayat, 2006). The most frequent ways for reducing spray drift include air-assisted spraying, electrostatic spraying, and the use of air induction nozzles and boomshields. It is not possible to modify the sprayer settings based on wind intensity during spraying with these approaches. Bayat et al. (2023) designed a unique servo-controlled spraying system was devised and developed to adjust the nozzle orientation angle in the opposite direction of the wind current in real time and automatically in a wind tunnel to eliminate ground spray drift. To evaluate spray drift, the displacement in the spray pattern (D_c) was employed as a ground drift indication for each nozzle. Via self decision making and mathematical models, the spray drift was decreased in aformentioned study (Figure 7).

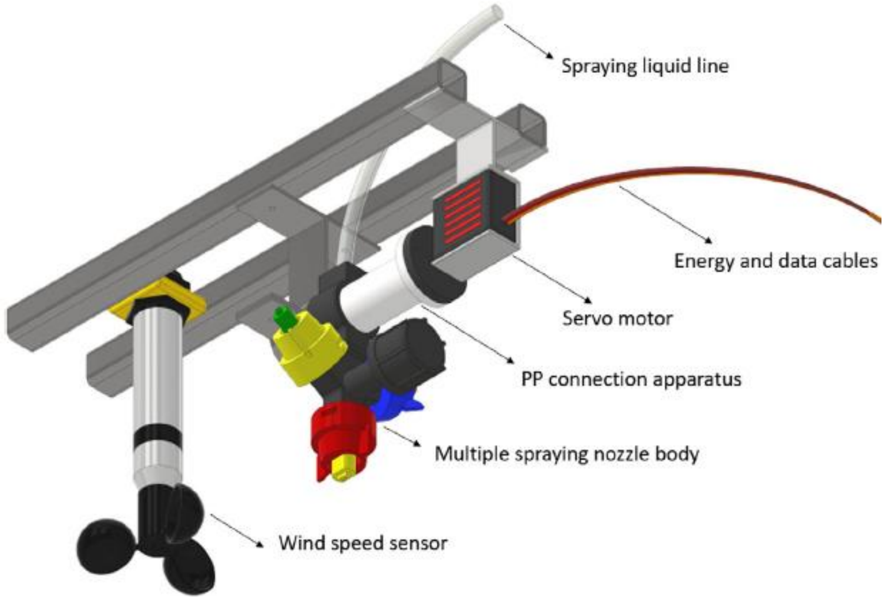

Figure 7. The system that can change the orientation angle of the spray nozzle (Bayat et al., 2023)

Harvesting Robots

Gathering mature crops from an agricultural field is referred to as harvesting. This method, however, differs depending on the crop. Harvesting horticulture crops, such as vegetable or fruit crops, refers to the collection of fruits or vegetables from plants, whereas harvesting rice or wheat crops is a distinct procedure. Harvesting necessitates significantly more labor hours; in horticulture, fruits and flowers must be harvested from plants periodically as they mature. A robotic harvester must identify produce attributes like as position, size, surface type, and shape. Furthermore, for the harvesting operation, the robot requires mobility to move to an appropriate place and a picking or harvesting mechanism. Fruit and vegetable picking robots are mechanical equipment used in modern agriculture for large-scale detection and picking of fruits and vegetables. To address these issues, several semi-automated harvesting equipment, including as harvesters and combine harvesters, have been constructed. Many commercially available harvesters can communicate with tractors by the aid of PTO. Combine harvesters, which are human-operated vehicles devoted to harvesting operations, have been used to harvest a variety of crops such as wheat, oats, barley, corn, soya beans, and sunflowers. Other robot types can be built for more broad uses, but harvest robots are both more expensive and more complex to design because they are designed directly based on the vegetative properties of the produce.

The vision system is the most significant component of a robotic harvester since it gives critical information about the fruit recognized as required by the harvesting components.

According to Bac et al. (2014), results of the review were ordered by the production environment (orchard, open field, greenhouse, or indoor) and by the particular crop on which the research had been focused. In summary, the review addressed the following questions:

- Which crops have been investigated for robotic harvesting?
- Which performance measures were reported and whichare relevant to assess a harvesting robot?
- What percentage of harvesting robots was autonomous?
- Which tested conditions were reported?
- What is the overall performance of robots developed so far?
- How does performance compare between production environments, crops, and over time?
- How did researchers carry out the design process interms of systematic design and economic analysis?
- What hardware components did researchers select?
- Which algorithms were reported for the main tasks offruit harvesting?
- Which robots contained adaptive algorithms, and did those perform better?

Robots' autonomy (true/false) and whether they underwent lab or field testing were the two performance metrics that were categorically measured. We defined a robot as autonomous if it accomplished tasks without human assistance after a human operator put it in the field and established the hardware and algorithm parameters at the beginning of each field test. The distinction between lab and field tests was deemed significant because a lab environment is typically far more structured than a field environment. As a result, in the lab, performance can be higher than in the field. The performance stated in field conditions is important since a harvesting robot will eventually be employed in field conditions.

A robotic method for collecting sweet peppers was created (Figure 8). One 6 DOF industrial manipulator with a specially built end effector, an RGB-D camera with GPU computer, programmable logic controllers, and a tiny container to hold picked fruit comprise the system.

Figure 8. Project of SWEEPER, a sweet pepper harvesting robot prototype (Arad et al., 2020)

CONCLUSION

Detection necessitates the measurement of particular parameters using an appropriate sensing methodology. Then, based on the parameter measurements, actions are conducted with an automated agricultural tool attached to the mobile robot. Uneven soil surfaces, unfavorable weather conditions, and the intricate and fragile structure of arable crops all contribute to erratic measurement mistakes and the complexity of designing a control mechanism to reduce the effects of errors when completing a task. Complete autonomy in arable farming will modify farming processes by removing or adding a task. The use of multiple robot coordination among various ground-based mobile robots or a combination of ground and aerial mobile robots can attain complete autonomy. To improve present agricultural robotic systems, four major areas of future research have been proposed: locomotion systems, sensors, computer vision algorithms, and IoT-based smart agriculture. Aside from autonomous machinery, improved control systems, and socioeconomic considerations, contact with the agri-environment is important to address. To enable more natural and user-friendly interaction in agricultural production, new approaches are necessary.

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