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SUSTAINABLE AGRICULTURE TECHNOLOGIES I

PROF. DR. ALİ BAYAT
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, blockchain, 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; In disease and pest control, it is important to apply pesticides with the right pesticide application technologies, taking into account the environmental risks (spray drift-reducing technologies), energy saving and protection of agricultural products from the effects of adverse climatic conditions (frost damage). Innovation in agriculture is critical to accomplishing long-term food security and increasing productivity. 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 of inputs in agricultural production, protect the product, and help farmers in their decision-making processes are discussed.

Prof. Dr. Ali Bayat / Editor

CHAPTER 1

ACTIVE FROST PROTECTION METHODS USED TO MINIMIZE FROST DAMAGE IN ORCHARDS

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INTRODUCTION

When plant tissue temperatures drop below critical values, sensitive perennials such as vines and pome fruit can suffer irreversible cold damage, causing plant cells to deteriorate or die. Very low temperatures can damage the physiological integrity of plant tissue. This damage can be in the form of radiation damage, either as a result of the expansion and freezing of the intracellular fluid that causes fragmentation in the cell (in the form of physiological frost damage), or as a result of the production of reactive oxygen species in the chloroplasts when plants are exposed to higher light levels than necessary for photosynthesis. The most important climatic parameter for plants is temperature. Optimum temperature requirements of plants are different. In general, plants develop optimally between 7 - 38 ^{o}C. The frost resistance of plants is different from each other. While olive can withstand -10 ^{o}C, citrus (Figure 1) can only withstand -10 ^{o}C for a few hours.

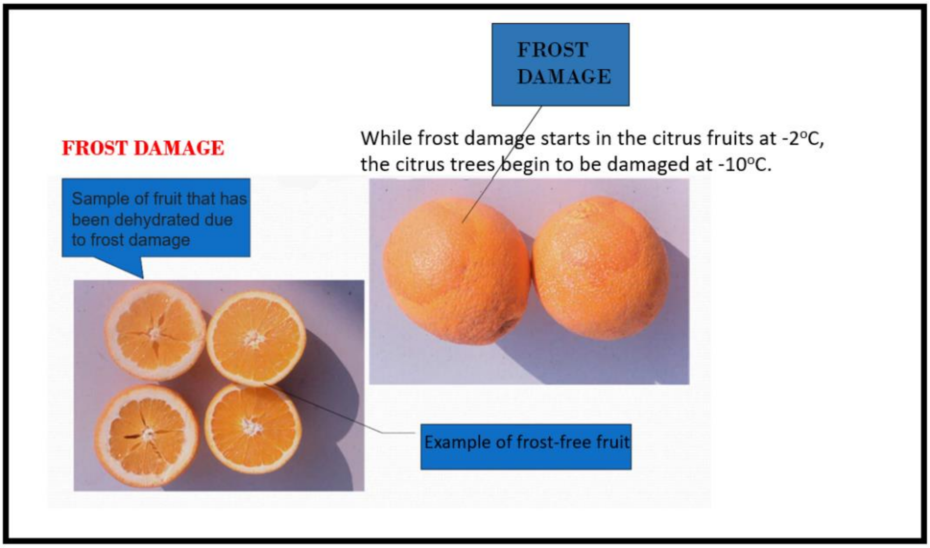

Figure 1. The damage of frost on citrus fruits

It is absolutely necessary to know the critical temperature values in order to protect the fruit trees and the product from frost. critical temperature; The amount of freezing is called "critical temperature" or "critical damage temperature" as the temperature drops and corresponds to a certain damage level. It is indicated by the symbol Tc (Table 1).

T_{10} and T_{90} values: Temperatures at which 10 percent and 90 percent of salable product production is likely to be damaged.

Table 1. Critical temperature values for some fruit trees

Fruit	**Vegetative Development**	**T_{10}**	**T_{50}**	**T_{90}**
Apple	Blooming	-2,2		-3,8
Pear	Blooming	-2,2		-5,0
Peach	Blooming	-2,7		-4,4
Cherry	Blooming	-2,2		-3,8
Plum	Blooming	-2,7		-5,0
Strawberry	Blooming		-1,1	
Grape	Twigging		-2,7	

Despite the impressive developments in agricultural technologies in recent years, agricultural production still depends on weather and climatic conditions. As long as agricultural technologies do not develop rapidly in parallel with global climate change, it is an obvious fact that climate variability will play a larger role in the agricultural production process compared to the past. The negative effects of climate change can only be partially compensated by the developments in agricultural technologies. Along with climate change, seasonal shifts may increase the risk of cold effects on crops in agricultural production. It is estimated that there is a loss of 5-15% of crops due to frost every year around the world. This is a very high rate of crop loss and is a serious concern to feed the growing world population. While frost damage in agricultural products does not occur in some years, only fruit, sometimes directly trees can be completely damaged, depending on the severity, which suddenly catches the producers who do not take precautions in the years when it occurs.

Concerns and consequences related to frost in agricultural production can be summarized as follows. frost event;

- Sensitive plants can be damaged when air temperatures drop below 0 °C, which has a significant impact on production.
- Frost damage causes more economic loss than other weather-related events.
- Impacts on Affected Producers and the local economy are often devastating.
- Although important, information on how to protect crops from frost is relatively limited.
- There is a need for widely available, simplified applications to help farmers solve this serious problem.

Examples of frost definitions in the literature include:

- the occurrence of a temperature less than or equal to 0 °C measured in a "Stevenson-screen" shelter (Fig.2) at a height between 1.25 and 2.0 m (Hogg, 1950, 1971; Lawrence, 1952);
- the occurrence of an air temperature less than 0 °C, without defining the shelter type and height (Raposo, 1967; Hewett, 1971);
- when the surface temperature drops below 0 °C (Cunha, 1952); and the existence of a low air temperature that causes damage or death to the plants, without reference to ice formation (Vitkevich, 1960).

Figure 2. Stevenson –screen shelter

Growers often use the terms “frost” and “freeze” interchangeably, with the vague definition being “an air temperature less than or equal to 0 °C”. Frost damage in Turkey occurs due to early autumn frosts, extreme cold in winter and late spring frosts. Early autumn frosts; It occurs because the trees do not prepare themselves for cold conditions enough, while winter frost occurs in cold temperatures lower than the cold temperatures that the tree can withstand in winter months. In the spring late frosts; It occurs due to sudden changes or low temperatures that may occur in the spring when the trees are physiologically extremely active and sensitive.

Types of Frost

The frost event takes place in the form of Advection (Wind) and Radiation frost.

Advection Freezes are typically associated with the movement of a weather front into an area. Cold and dry air replaces the warmer air that was present before the weather change. The passage of an advective freeze front is associated with moderate to strong winds, no temperature inversion, and low humidity. Temperatures will drop below freezing and stay that way for an extended period. It’s difficult to protect against advection freezes (. The winds associated with advection freezes blow added heat away and cause ice to form poorly, thereby limiting the effectiveness of frost protection systems. (Fig. 3 & 4). It is not possible to protect plants grown in open areas in such frosts (Smith et al., 2017).

Radiation Freezes happen When the sky is clear and there is little to no wind, radiation freezes occur. Heat loss in the form of radiant energy causes radiation freezing. Consider a rock in the sun that starts to lose heat when placed in the shade: cooling is the loss of radiant energy. An atmospheric temperature inversion (Fig. 5) is frequently linked to radiation freezes. When air temperature rises as elevation rises, a temperature inversion happens. Since temperatures typically drop as elevation rises, this is referred to as a "temperature inversion.". The "peak of the inversion" is the elevation at which the temperature starts to fall, according to meteorologists. When temperatures above are only marginally warmer than those below the surface, an inversion is weak. Temperature increases with elevation that happen quickly are a sign of a severe inversion. During strong inversion circumstances, frost prevention strategies are more effective.

Figure 3. Advection frost formation form
https://legacy.climate.ncsu.edu/edu/FrostFreeze)

Figure 4. Advection frost damage in lemon orchards in March 2022 in Karataş region Adana /Turkey

Radiation frosts are the most common type of frost. They are characterized by clear skies, calm or little wind, temperature variation, low dew point temperatures and air temperatures that fall below 0 °C during the night but above 0 °C during the day (Figure 5).

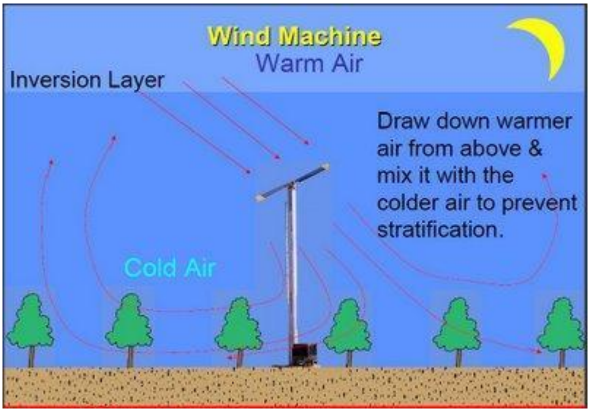

Figure 5. Formation of radiation frost (https://legacy.climate.ncsu.edu/edu/FrostFreeze)

Classification of Frost Protection Methods

Frost protection methods can be divided into two classes as passive and active protection methods. Passive protection includes methods applied before the night of frost to eliminate the need for active protection. However, Active methods are those that are activated during frost and often require an energy expenditure. The main passive methods are:

- site selection;
- managing cold air drainage;
- plant selection;
- canopy trees;
- plant nutritional management;
- proper pruning;
- plant covers;
- avoiding soil cultivation;
- irrigation;
- removing cover crops;
- soil covers;
- trunk painting and wraps
- bacteria control; and
- planting date for annual crops.

Passive methods are usually less costly than active methods and often the benefits are sufficient to eliminate the need for active protection.

Active protection methods include:

- Heaters,
- Wind machines,
- Helicopters,

- Sprinkler (sprinkler),
- Surface irrigation,
- Foam insulation,
- Foggers,
- Chemical Freeze Protectors;
- Combination of Active Methods

Active Protection Methods of Frost Protection

Heaters

Orchard heaters have been used for centuries. A common commercial type is a return flue fuel oil operated heater (Figure 6). It is recommended to use one per $100m^2$ area for frost protection in fruit trees (Smith et al., 2017). However, the amount of pollutants released into the atmosphere as smoke, the cost of fuel and the effort spent on maintenance limit the use of these heaters. Orchard heaters have a strong inversion effect, but lose inversion effectiveness in windy conditions.

Figure 6. Vented type fuel-oil heater (Smith et al., 2017, Leonard and Kepner, 1950)

Solid, liquid or gaseous fuels are used in heaters used in orchards, depending on the heater feature. Especially solid and liquid fuel heaters emit smoke and create air pollution due to the CO and CO_2 they emit. Heaters provide freeze protection to the surrounding plants by direct radiation and cause convective mixing of heat within the inversion layer of the air. In Figure 7, the heat dissipation situation of a typical heater to the working environment is shown figuratively.

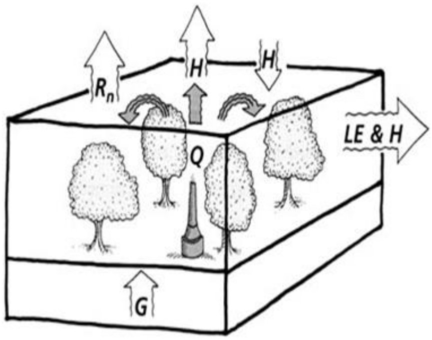

Figure 7. Representation of heat dissipation and heat parameters generated from a typical heater

Rn : Net radiation

H : Vertical and horizontal sensed heat flux

G : Ground conductive heat flux

LE : Latent heat

Q : additional heat emitted by the heater

Known as latent heat, a chemistry term, sensible heat is the amount of heat given or received to change the temperature of any body. The heat that changes the temperature of the air without changing the moisture content is called sensible heat. The air temperature leaving a heater in the orchards between 635 °C and 1000 °C. Therefore, after leaving the heater, the air rises quickly into the less dense air. When heated air rises, it mixes with cooler air, warming the surrounding air (Fig. 8).

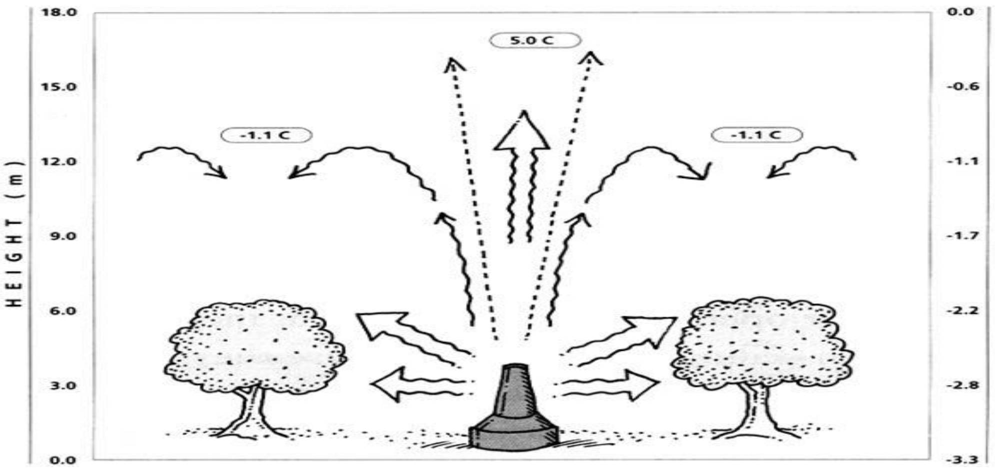

Figure 8. The temperature change in the environment with the vertical movement of the hot air flow leaving a heater (Snyder& Melo-Abreu, 2005).

Smoke effect heaters

Smoke produced by smoke-generating heaters (Figure 9) covers the sky and reduces visibility. However, they have an insignificant effect on the apparent sky temperature. The average smoke particle size is less than 1.0 mm in diameter. The smoke created reduces radiation in the visible range (0.4-0.7 mm), but has little effect on the transmission of long-wave radiation. Therefore, long-wave radiation upwards from the surface mainly passes through the smoke without being absorbed. In this case, heat rise from the soil by radiation cannot be prevented**.**

Heater requirements

Liquid fuel heaters: provide 38 MJ/L (mega joules/liter).

Energy output: 140 to 280 Wm^{-2} (5.0 and 10 GJ $ha^{-1}hr^{-1}$).

Fuel requirement: It ranges from 133 to 265 liters $ha^{-1}h^{-1}$(L/ha.h).

For more effective protection, it is best to keep fuel consumption low and use more heaters per heater.

Figure 9. Heaters

Heater placement and management

- If the plant is located on a slope, more heaters should be placed upstream where the cold air is discharged into the plant (Figure 10).
- Under freezing conditions, when the wind speed exceeds 2.2 ms^{-1} (7.9 km h^{-1}), significant heat loss occurs due to horizontal convection and higher heater concentrations are required to the wind limit.

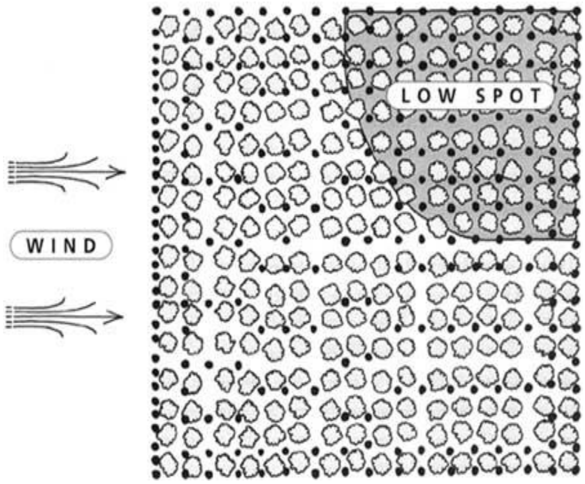

Figure 10. Example of heater layout (Snyder& Melo-Abreu, 2005)

Liquid fuel heaters

- Liquid fuel heaters were developed in the early 1900s for frost protection.
- Typically there are about 75 to 100 oil heap heaters or 150 to 175 propane fuel heaters per hectare.
- A well designed and operated heater system produces approximately 1.23 MW ha^{-1} (ie 123 W m^{-2}) of energy.
- 8 liters h^{-1} per heater for oil and kerosene fired heaters, approximately 1 m^3h^{-1} for propane fueled heaters.
- Oil fired heaters should be cleaned after every 20 to 30 hours of operation, and the heaters should be turned off to prevent the ingress of rainwater that could cause oil to leak onto the floor.

Propane-fuel and natural gas-fired heaters

- Labor requirements for filling liquid fuel heaters are high, so some manufacturers have switched from the use of individual heaters to centralized distribution systems**.** The system uses hoses to transport fuels to the heaters. The fuel can be natural gas, liquid propane or fuel oil..
- In more complex systems, ignition, combustion rate and shutdown are automated in addition to fuel distribution.
- Central systems have high installation costs, but low operating costs.
- Since the burning rate is less, more heaters are needed.
- About 130-150 heaters are required per hectare, but protection is better.

Solid fuel heaters

- For example; wood, coal and coke.
- Solid fuels were used as a frost protection method before liquid or gaseous fuels.
- The main disadvantage of solid fuels is that the energy release decreases when the fuel is depleted and thus becomes most limiting when there is a need for energy liberation.
- Another disadvantage is that solid fuels are difficult to ignite, so they need to be started early. It's also hard to extinguish, so fuel is wasted when it starts unnecessarily.
- The use of two oil waxes under each grapefruit tree resulted in an average increase of 1.7 °C for the fruit.
- By using 375 bricks of petroleum wax and coke per hectare, an increase of 2.2 °C was observed at 1.1 m height.

Mobile heater

It uses four 45 kg propane tanks to supply fuel, which is mounted on the back of a tractor (Figure 11) for the heater. After starting the heater, the fuel supply is adjusted to give a temperature of about 100 °C where they vent from the machine.

Figure 11. Mobile heaters

Wind Machines

Wind machines (or fans) that blow air almost horizontally were introduced in California in the 1920s as a method of frost protection. However, it was not widely accepted until the 1940s to 1950s. Now these are widely used in many parts of the world. Wind machines (Figure 12) are used on a wide variety of crops, including vines, deciduous trees and citrus. Wind machines are only effective in radiation frost. In Figure 13, the air layer movements in the orchard during the day and the night when there is radiation frost and the effect of the wind machine are given. The components and some dimensions of a typical wind machine are as follows.

- Wing diameter: 3-6 meters.
- Height: 10-11 meters.
- Propeller rotation speed: 590-600 rpm.

- Number of propeller blades: 2 or 4.
- Propeller rotation around its axis: 4-5 minutes.
- Fan tilt angle: 5-7º.
- Engine: The engine that rotates the propeller is located above in old propellers and below in new propellers.

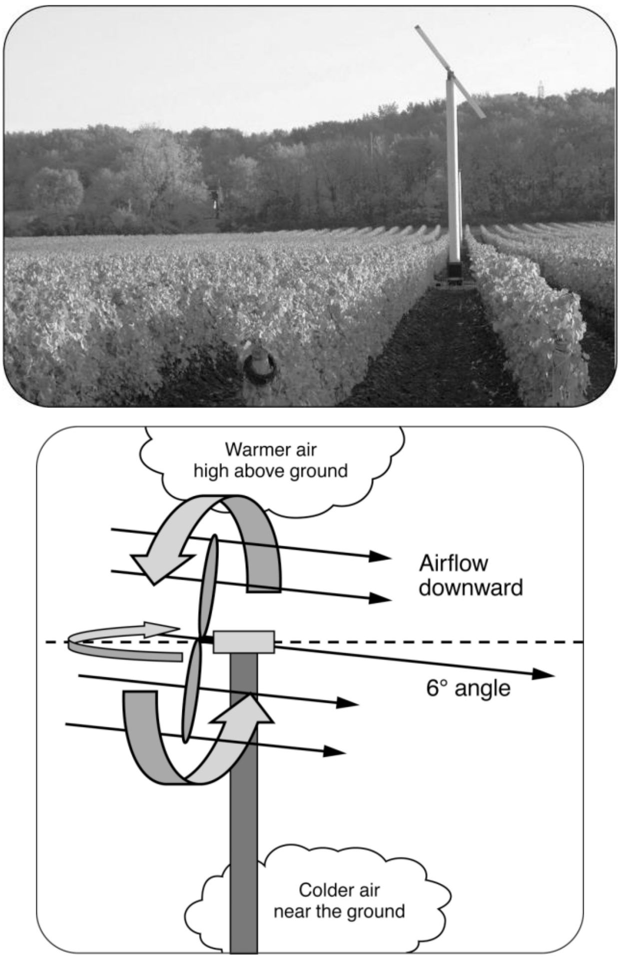

Figure 12. Wind machine example. (Fraser, 2010)

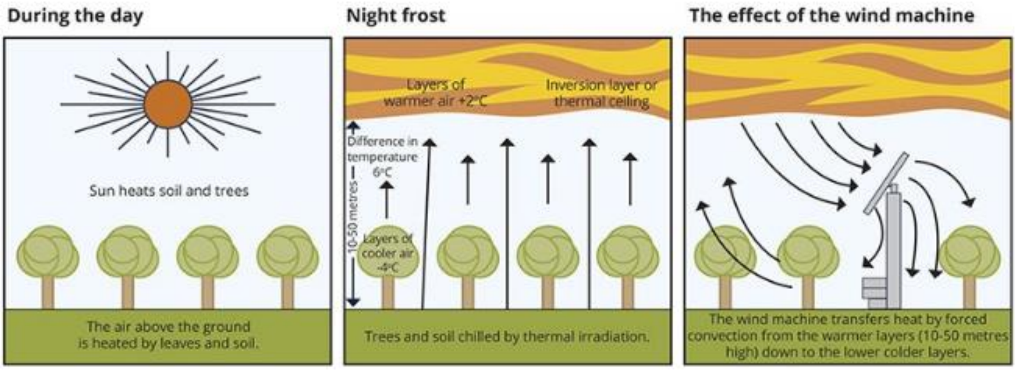

Figure 13. Radiation freeze formation and the effect of wind machine on frost protection **(**https://www.nzfrostfans.com/about-frosts/)

A schematic diagram showing the effect of wind machines on the temperature profile during radiation freezing is given in Figure 14.

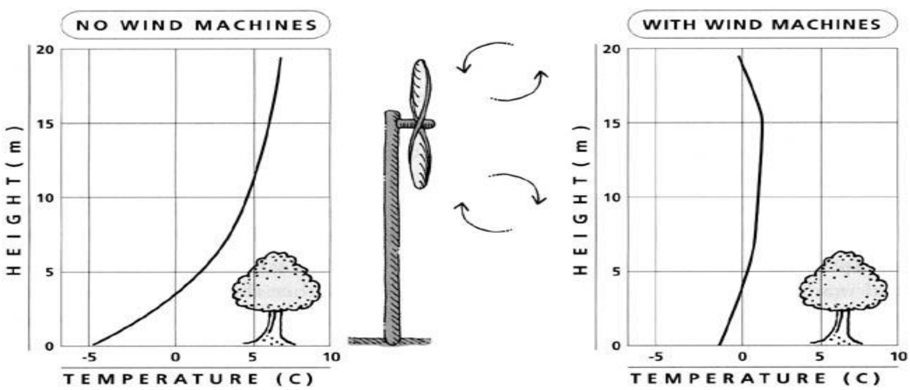

Figure 14. Air temperature variation in vertical direction with wind machine deactivated (a) and starting (b) (Snyder& Melo-Abreu, 2005)

Wind machines usually require a 75 kW wind machine for every 4 to 5 ha. For example, a radius of about 120 to 125 m. If a wind machine is used, approximately 18.8 kW of motor shaft power per hectare is usually required. When using various machines, a motor shaft power of about 15 kW per hectare is recommended. Wind machines are typically started when the air temperature reaches about 0°C or critical damage temperature. When the temperature at 2 m above the ground is equal to the temperature at 10 m, the wind machine is turned off.

Best Management Techniques for Running Wind Machine

The following best management practices for using wind machines should be used by grape and orchard farmers in order to maximize efficiency and reduce noise pollution (Fraser, 2010).

Crop hardiness

- Take care of your plants to keep them as healthy as possible as winter approaches.
- When deciding whether to use a wind machine, use the most recent data on plant hardiness and take into account key plant temperatures.

Location of wind machines

- Place wind turbines where they will take into account terrain and wind direction's projected skewing effects on the areas under their influence.
- When positioning wind machines, take into account nearby wind machines and any characteristics that might offer further protection from the effects of the cold, such as roads, warm structures, streams, or wooded areas.
- Plant crops that are more susceptible to cold damage as far away from neighbors' homes as you can so that wind turbines can be placed away from their residences.

Monitoring

- Use the best local weather forecasts available.
- Monitor continually for strong temperature inversions, greater than 3˚C, on or near the farm to determine if operating machine(s) might provide some plant protection from cold injury. This includes a tower at least 10 m high to monitor air temperatures above the crop.
- Set start-up temperatures for wind machines based on sensors located below the fruiting wire and within 15 m of each machine.
- Monitor and automate start up/operation/shut down of wind machines, using a combination of real-time remote air temperature/wind speed/wind machine operation sensing devices and monitoring via cellphones/computers/pagers, etc.
- Set start-up air temperatures as close as practical to expected critical air temperatures — Spring frost: 2°C–3°C Fall frost: 1°C–2°C Winter: variable based on latest bud hardiness data from local freezing trials.
- Set the differential (wind machine stop temperature) 2°C–3°C higher on wind machines than for start-up temperatures.

Wind

- If wind gusts exceed 7 km/h, avoid using wind machines because it is doubtful that there will be a significant temperature inversion or warmer air above the field.
- Avoid using wind machines when the wind speed is 13 km/h or greater because this can harm the long, thin blades.
- Never use a wind machine when the wind speed is 21 km/h or greater because doing so could severely harm it.

Maintenance

Inspect wind turbines annually to ensure they are in good functioning condition. This entails performing routine engine maintenance, changing the gearbox oil (at the base and top of the tower), lubricating the drive lines, inspecting the seals, making sure that all tower bolts are tight, checking the blades and attaching hardware, and keeping booster cables handy for emergency use.

Noise

- In agricultural regions, place wind machines as far away from neighboring houses as is practicable, but no closer than 125 m unless optimal management methods are followed.
- Provide a 24-hour cellphone number for them to call, and explain how and why wind machines work to neighbors who live within 125 meters of a machine.
- Set the wind machines nearest to the neighbors to turn on and off last and first.
- Exercise caution when operating wind machines on farms in areas where you do not reside because you may not always be present to observe their operation.
- Install all wind machines with mufflers.

Helicopters

Helicopters move the hot air in the opposite direction towards the surface. Due to large standby and operating costs, helicopter use for frost protection is limited to high value crops or emergencies (when the normal method collapses). Estimated coverage ranges from 22 to 44 hectares. Passes need to be made every 30 to 60 minutes, under more severe conditions more passes. The optimum height is usually between 20 and 30 m. Common flight speed is between 25 and 40 km h^{-1} or 8 to 16 km h^{-1}.

Sprinklers

The use of sprinklers/sprinklers (Figure 15) for frost protection has an advantage over other methods where water application is generally less expensive. The energy consumption is considerably lower than that used for frost protection with heaters.

Figure 15. Example of frost protection with sprinkler irrigation

Irrigation

One of the most common methods of frost protection is the direct application of water to the soil using graduated confinement or flood waters (Figure 16). The earliest known research on using surface waters found a 1°C increase in air temperature in a citrus hut flooded with 23°C water.

Figure 16. Example of frost protection with surface irrigation

Foamed thermal insulation

Applying foam insulation to low-growing plants for frost protection has mostly been studied in North America and has been shown to raise the minimum temperature up to 12°C. However, the method has not been widely adopted by growers due to the problems of handling large areas due to material and labor cost and inaccurate short-freezing estimates. On the other hand, it causes the spread of fungal diseases.

Foggers

Fog lines are known that use high-pressure lines and special nozzles to make fog droplets (10-20 mm in diameter), which are reported to offer good protection in calm wind conditions. They provide protection by blocking short wave radiation in the sky. A high-pressure fog generator is given in Figure 18.

Figure 18. High pressure fog generator (Snyder& Melo-Abreu, 2005)

Chemical frost protection

Two chemical frost protection methods are commonly used. The first is applying copper-based sprays, which kills ice-nucleating bacteria on the surface of leaves. Ice-nucleating bacteria such as Pseudomonas syringae can initiate ice formation on leaf surfaces, resulting in frost damage at or slightly below 0 °C (Lindow et al., 1978). The application of a spray to completely remove these bacteria from leaves, in theory, would allow plants to become supercooled and offer some protection from freeze damage. In closely managed experiments, the application of copper-based products and other antibacterial sprays have been shown to cause a significant reduction in ice-nucleating bacteria on leaves, but there was not a corresponding decrease in ice formation, suggesting that there were other non-bacterial compounds present that caused ice nucleation (Constantinidou et al., 1991). Because of the presence of non-bacterial sources of ice nucleation and the inability to completely kill ice nucleating bacteria in a field situation, the use of chemical frost protection has produced mixed results (Snyder and Melo-Abreu, 2005). Other commonly used chemicals for freeze protection are antitranspirants. When applied to plants, they are said to prevent ice nucleation or desiccation of leaves during a freeze. There is limited research-based information for the use of these products. In North Carolina, an experiment was conducted to identify the effectiveness of a commonly available antitranspirant as a frost protectant for tomatoes and peppers. It was reported that the product had no positive effects for frost protection (Perry et al., 1992). It should also be noted that freeze damage in plants results from ice crystals that rupture cellular membranes, resulting in the collapse and internal dehydration of cells, not water loss through stomata (Snyder and Melo-Abreu, 2005).

Combination of Active Methods

Combinations are methods that are generally applied by using two active methods together. For example; Wind machines and under-plant sprinklers, Wind machines and surface irrigation, Wind machines and heaters, Sprinkler and heater combinations can be used.

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CHAPTER 2

ELECTROSTATIC AND ASSESSMENT OF ITS SOME AGRICULTURE SPRAY APPLICATIONS

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INTRODUCTION

Charging the spray particles with static electricity was well employed in the industrial field. The technique was used successfully in the industrial field, especially, for the paint coating to more efficiently paint a workpiece. Accordingly, many attempts began to exploit this technology in pesticide applications. Several studies have demonstrated the ability of pesticide droplets charged with static electricity to increase the deposition on plants and reduce environmental pollution. The attraction between pesticide droplets charged with the static electricity and plant leaves occurs under the effect of inducing the opposite electric charges on these leaves when the charged spray cloud approach from plant Figure 1.

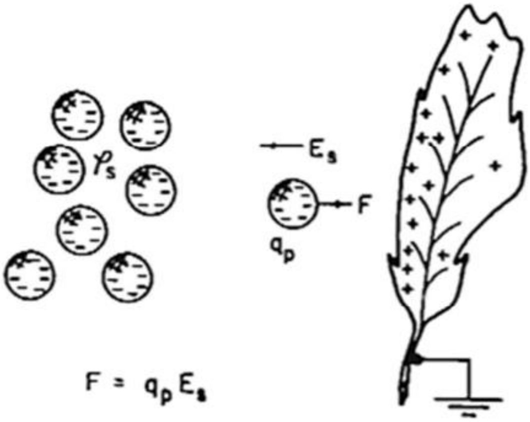

Figure 1. Inducing the electric charges on the plant under the effect of the nearby oppositely charged droplets (S. E. Law, 2018).

According to (Lane & Law, 1982), the electric charge flow current inside the plant trunk can occur in three cases; the movement of the electrically charged cloud, the deposition of charged droplets, or corona discharge currents, as shown in Figure 2. The first case results from the electrostatic sprayer movement closer to the plant. The charged cloud sprayed from this sprayer creates a gradually increasing electric field between itself and the earthed leaves' surface. That cause flows electric charges from the earth to the leaves to maintain a ground-potential equilibrium. The second result from depositing of the charged droplets on leaves that cause discharge their electric charges and move throughout the plant as electric current. Finally, electrical charge flow results from an unwanted corona discharge because of a charged cloud's local ionization under the effect of the increase in the electric field strength around pointed objects such as leaf tips.

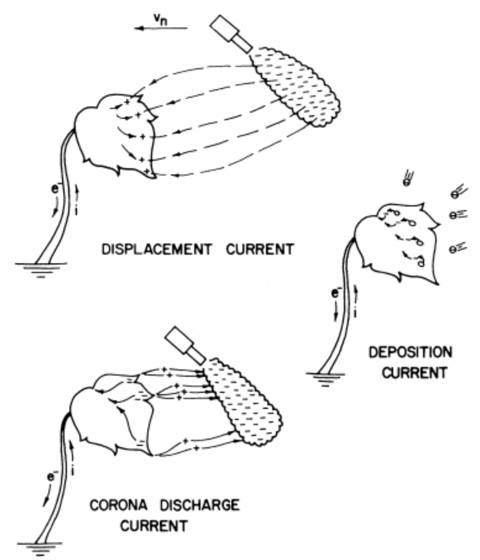

Figure 2: Direction of charge flow for the displacement-, deposition-, and discharge-current components within a living plant undergoing electrostatic spraying (Lane and Law, 1982).

The Advantages/Disadvantages of The Electrostatic Spray Method

The electrostatic spraying technique can provide many advantages when it is well employed in agricultural pesticide applications. (Arnold, 1983) found that electrostatic spraying can decrease the water and pesticide amount to half in a study about electrostatic pesticide applications on the cotton plant.

Similarly, (Kang et al., 2004) found that the deposition amount on leave surfaces of apple trees increased two times. Also, the electrostatic spraying system developed by (Yamane & Miyazaki, 2017) can reduce the pesticide amount used to vegetable production by 30%. Also, The repulsion forces between charged droplets in the electrostatic spray increase the distribution uniformity of pesticide droplets on the plant targets Figure 3.

Figure 3: Distribution uniformity of pesticide droplets on the plant targets.

The most important advantage of electrostatic pesticide applications is reflected in the increased deposition of droplets on invisible targets like the under surfaces of plant leaves and the hidden targets inside the intense plant canopy. A study conducted to exploit an electrostatic spray technique in agricultural pesticide applications to improve pesticide deposition (S. E. Law & Bowen, 1966) found that this technique can increase the chemical amount on the leaves under surfaces by 3.8 times. (Esehaghbeygi et al., 2010) found that the electrostatic sprayer improves the herbicide efficacy in the dense canopy, and the charged droplets can penetrate through dense weeds compared with the traditional spinning-disc nozzle. Similarly, (Pascuzzi & Cerruto, 2015) noted that electrostatic pesticide spraying increases the deposition by 50% on the underlayer and only by 12.5% on the upper layer.

Pesticide electrostatic applications improve the amount deposited on the leave surfaces; thus, less chemical is lost as drift in the surrounding environment. Reducing environmental pollution includes decreasing the high level of inherent noise from the fan blades of traditional orchard sprayers (Bayat et. Al., 2006; Itmec and Bayat, 2021). Most electrostatic sprayers have new designs that limit this annoying noise Figure 4.

Figure 4: Two sprayers, traditional with fan blades and electrostatic without blades.

Also, the electrostatic sprayers, especially those that use the induction charging method without connection between the induction electrode and the spray liquid, can charge the pesticide droplets with minimal electric power. (Patel et al., 2017) developed an air-assisted electrostatic nozzle that can charge the spray droplets up to 10 mC/kg charging efficiency using only 2.5 kV electrode voltage and power consumption less than 75 mW.

Despite the ability of the electrostatic sprayer to improve droplet deposition on plant targets and reduce environmental pollution by charging pesticide droplets with a small amount of machine power, the electrostatic spray technology has many disadvantages that limit its widespread use in agricultural applications. For example, electrostatic sprayers are so expensive compared with traditional ones. Thus, it is not purchased by the farmers who apply the pesticides a few times a year. Also, the induction charging method widely used for agricultural electrostatic applications requires a source of air current with velocity appropriate to remove the droplets deposited on the electrode surface and solve the problem of electrode wetting. (Frost & Law, 1981) noted that the required energy for the developed air-assisted electrostatic nozzle at 2.5 bar air pressure and 2.75×10^{-3} m^3/s airflows reached 350 W (0.47 HP) of tractor's energy; that equals 3500 times greater than the electric power wanted to charge the droplets. One of the disadvantages of pesticide applications by electrostatic sprayers is the need for regular maintenance to keep the nozzles clean and to ensure the continuity of electrical connections and appliances.

Charging Methods of Spray Droplets

Liquid spray droplets can be charged with static electricity when the liquid jet near the nozzle outlet undergoes a sufficient electrical field for collecting the electric charge on the liquid surface. As a result, liquid droplets charged with either a positively polarized or negatively polarized charge would be produced, depending on the charging method and the electrical signal of the high voltage generator. Spray droplets can be charged with static electricity by three-way Corona, Conduction, and Induction methods. Corona charging way can be used to conductive and non-conductive pesticide liquids by ionic bombardment (Patel, 2016). Induction and conduction charging is limited to semi-conductive and conductive pesticide liquids (E. Law, 2014; Zhao et al., 2005).

Corona Charging Method

Corona charging depends on separating the air adjacent to the liquid jet into positive and negative ions by a pointed electrode placed at the nozzle outlet and connected with a very high voltage source, as shown in Figure 5. Subsequently, the pointed electrode attracts ions with the opposite sign, while ions with the same sign rush towards the liquid jet and charge droplets with the same electrical polarity. Droplet charging level is affected by many factors, including electrical properties and surface area of the spray liquid, and the duration of time a droplet stays inside the ionization field. Air ionization in this method requires high electrode voltage levels; thus, using this method in agricultural pesticide applications is dangerous to the farmer's life. Especially most pesticides use water as a carrier in agricultural applications that has high conductivity values. Therefore, insulating the whole tank liquid of the electrostatic sprayer in addition to high voltage parts is necessary. That makes using the corona way inappropriate for pesticide applications. However, some studies tested this way to develop an electrostatic sprayer. (Arnold & Pye, 1980) developed an electrostatic spinning disc that charges the spray droplets with 30 kV high voltage applied to a pointed electrode. Also, (Ganzelmeier & Moser, 1980) used this way to develop an electrostatic hydraulic nozzle with high values of the electrode voltage until 130 kV.

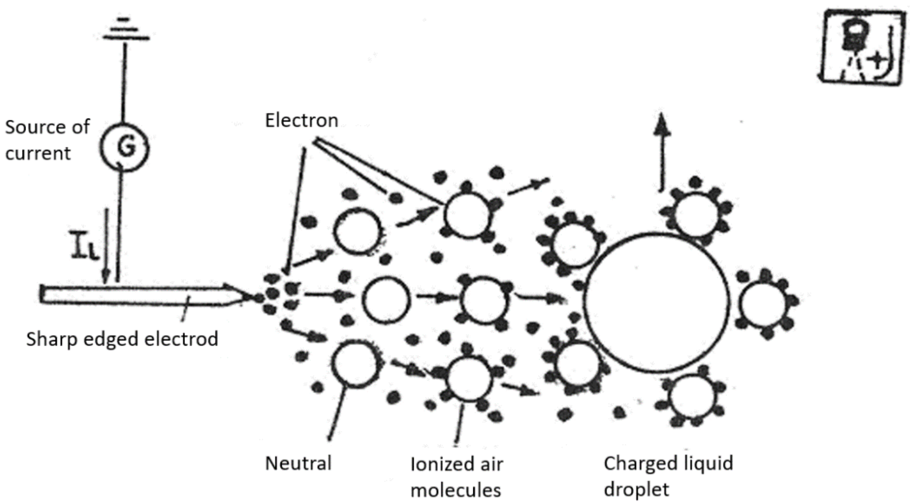

Figure 5 : Corona charging method.

Contact Charging Method

In this method, the high voltage is applied to liquids directly or by metal nozzles, as shown in Figure 6. It is used for the electrically conductive or semi-conductive liquid that provides spray droplets charged with the same sign of high voltage signal. (Zhao et al., 2005) found that spray droplets can be charged more significantly than the induction method. However, The risk of the conduction between the high voltages and tank liquid made this method unfavorable for agricultural applications.

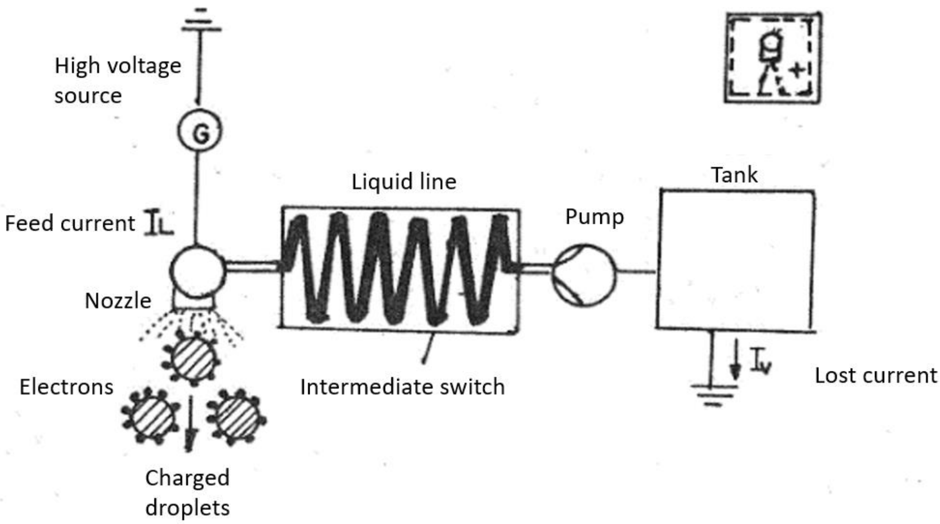

Figure 6: Contact charging method.

Induction Charging Method

The induction charging method depends on inducing the electric charges from the ground to the liquid jet surface. When the induction metal electrode with a high voltage is placed close to the grounded conductive liquid jet without touching it Figure 7 and Figure 8, electrical charges with opposite polarity are induced on the surface of this jet. The spray droplets separated from this liquid jet will carry a part of these electrical charges, and thus they will be charged with opposite polarity from the induction electrode (S. E. Law & Bowen, 1966).

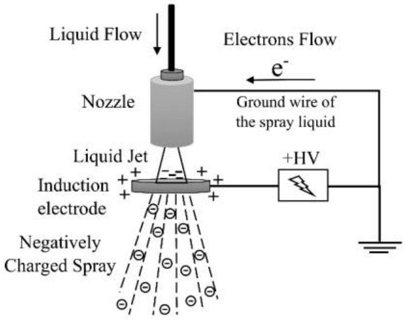

Figure 7: The principle of the induction charging method with +HV (Amaya & Bayat, 2021).

For example, when the induction electrode is connected with a positive high voltage source, it will induce a negative charge by attracting the electrons from the earth to the surface of the conductive liquid jet Figure 7. Also, if the electrode were connected with a negative high voltage, electrons would be repelled from the conductive spray liquid jet to earth, and thus the spray would be positively charged Figure 8.

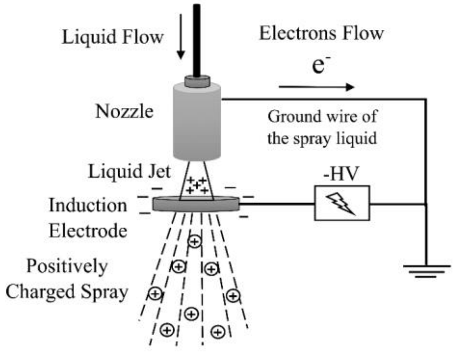

Figure 8: The principle of the induction charging method with –HV (Amaya & Bayat, 2021).

Most researches about electrostatic charging applications in the agricultural fields use the induction charging method to develop the electrostatic system. It is considered appropriate to pesticide aqueous with high electrical conductivity. The absence of electrical contact between the pesticide liquid and the high voltage induction electrode removes the electric shock hazard to farmer's life and reduces the electric current consumption drawn from the high voltage generator (S. E. Law, 1978; S. E. Law & Bowen, 1966; S. E. Law & Cooper, 1987).

Evaluation of the Charging Efficiency in The Laboratory:

The spray droplets' charging efficiency is usually evaluated in the Charge-to-Mass Ratio (CMR). It determines the amount of electric charges per mass unit of the spray droplets. The measurement ways of charge-to-mass ratio are categorized into static and dynamic methods. The static method depends on measuring the electric charge of whole spray droplets by a Faraday cage. The dynamic method measures one particle's motion parameters to an electric field (Brown, 1997). Faraday cage (first way) is usually used to evaluate the charging efficiency in agricultural electrostatic spraying experiments.

Figure 9 shows the measurement method of the charging efficiency of spray droplets by the faraday cage. When the charged droplets touch the mesh layer, the electric charges discharges from these charged droplets to the Aluminum wires. The Aluminum tray discharges droplets passing through the first layer and still contains residual electric charges. The electric charges move throughout the Aluminum wires and the tray into the ground and cause an electric current detected by the digital multimeter. The charge-to-mass ratio is calculated by dividing the previous spray electric current by the mass flow rate as shown in equation (1):

$$\text{Charge-to-mass ratio (CMR)} = 60\times I_s/Q_m \qquad [\text{mC/kg}]$$

The following units are used for the terms charge and mass:

Spray current: I_s [μA].

Mass-flow rate of the spray liquid: Q_m [ml.min^{-1}].

Where 1 liter of tap water was considered equal to 1 kg.

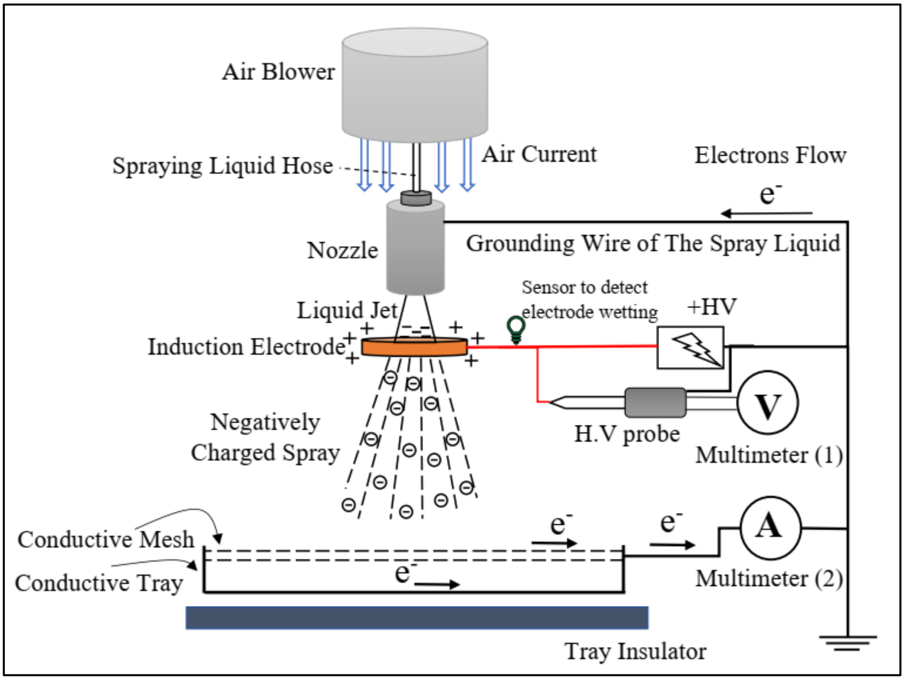

Figure 9: a scheme showing the measurement way of the charging droplet by the Faraday Cage method (Amaya & Bayat, 2021).

Many studies used the Faraday cage technique to evaluate the charge-to-mass ratio. These Faraday cages were manufactured with different designs according to experiment requirements. (Mamidi et al., 2012, 2013; Patel et al., 2015) used Faraday cage which has dimensions 600x300x300 mm and 6 layers of good electric conductive meshes. (Khatawkar, Dhalin, & James, 2020; Khatawkar, Dhalin, James, et al., 2020) used a Polypropylene vessel that contains an Aluminum mesh to receive the charged droplets from the electrostatic nozzle. The vessel was shielded from atmospheric electric field interference with earthed Aluminum mesh wrapped around the out surface of this vessel. (Jahannama et al., 1999) used two concentric metal cylinders to manufacture the Faraday cage. The inner cylinder with two metal wire screens placed inside it was used to collect the charged spray. While the outer cylinder was earthed and used as a shielding layer for charged droplets from the electric field effects existing in ambient air. (Amaya & Bayat, 2021) used a Faraday cage that consists of a 1300×1300 mm Aluminum tray, 80 mm deep, and a two-layer aluminum mesh, as shown in Figure 10. The device was manufactured in the workshop of the Agricultural Machinery department at Çukurova university, and it is installed in the spray laboratory Figure 11.

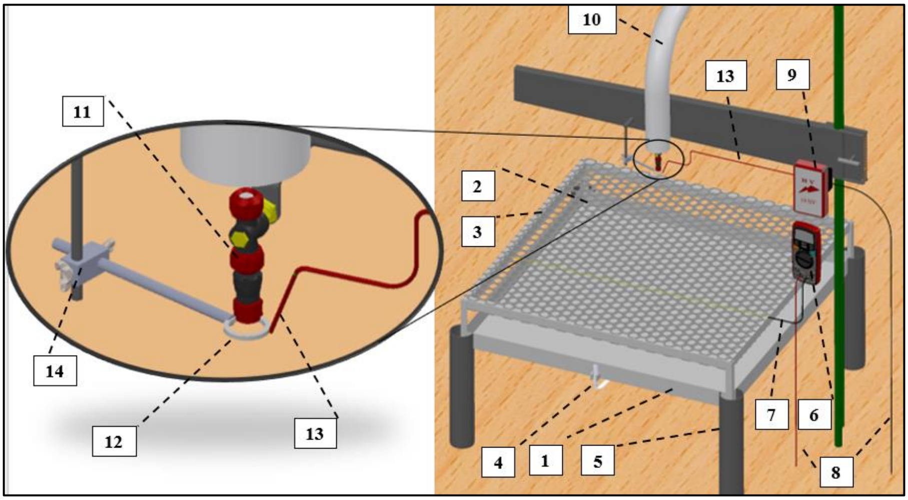

Figure 10: The drawing of the Faraday cage by SolidWorks software.

1-aluminium tray, 2- Two layers of aluminum mesh, 3- Aluminum square profile, 4- Plastic hose to drain the water after each experiment, 5- Four plastic feet for electrical insulation of the aluminum tray, 6-multimeter, 7- Cable attach the Faraday cage with the multimeter, 8- Grounding cables, 9- High voltage source, 10- Air blower, 11- Hydraulic nozzle, 12- Charging electrode, 13- High voltage cable, 14- A tool to adjust the distance between electrode and nozzle tip.

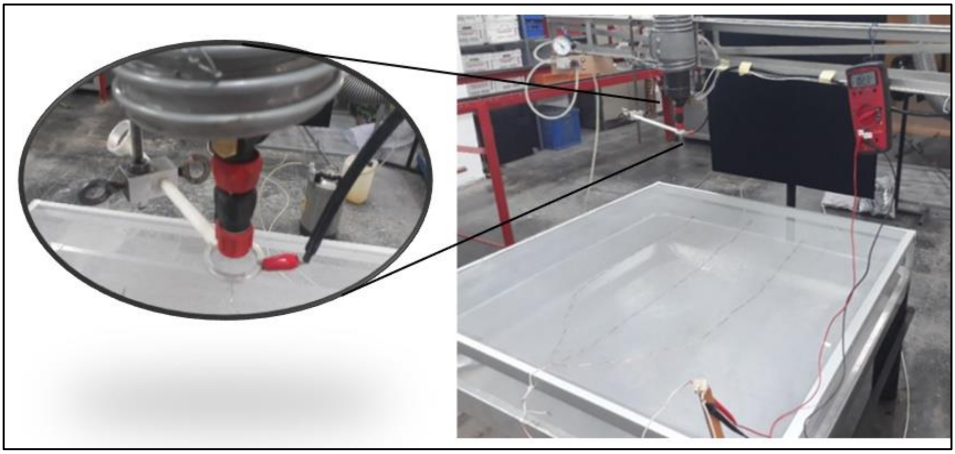

Figure 11: Faraday Cage used to determine the charging efficiency.

Some agricultural studies about the development of the electrostatic spraying systems :

There are various studies on developing electrostatic sprays for more efficient applications of pesticides and reduced chemical drift. (S. E. Law, 1978) designed an air-assisted electrostatic nozzle to charge spray droplets with an embedded induction electrode. Charing efficiency of this nozzle reached 4.8 x 10-3 coulombs. kg-1 at a liquid flow of 80 ml.min-1 and 2 kV electrode potential. (Inculet et al., 1981) developed the traditional orchard sprayer into an electrostatic sprayer. The new machine can provide 85% more pesticide than the mechanical one for both the upper and lower tree parts. (Herzog et al., 1983) evaluated the air-assisted electrostatic nozzle developed by (S. E. Law, 1978) in cotton fields. Experimental results showed that the electrostatic sprayer can provide the same insect control but only with a 1/2 rate of the pesticide. (BAYAT et al., 1994) conducted a study in Adana aimed to replace old spray handguns used for pesticide applications with newer spraying techniques. The electrostatic air-assisted sprayer with 17 kV electrode voltage was used as one of the alternative equipment to pesticide applications used in this study. Electrostatic charging increased the deposition, especially in W. Navel trees, but could not reduce deposition variability at the chosen zones on the tree in the vertical direction. (Kirk et al., 2001) evaluated the prototype aerial electrostatic spray nozzles developed by (Carlton, 1999) mounted on agricultural aircraft (Cessna T188C AgHusky) in increasing the spray deposition. Experimental results on cotton fields showed that the droplet deposition was higher with the electrostatic sprayer. (Laryea & No, 2003) developed an electrostatic nozzle that consisted of a hydraulic nozzle and a ring induction electrode manufactured from brass material. The charging efficiency was 0.27 mC/kg at a 69 ml/min liquid flow rate. The electrostatic devices increased the deposition amount by 1.3–2.3 folds at 60 cm nozzle height from the target. However, no significant difference in deposition amount was noted at 90 cm height. (Kang et al., 2004) used electrostatic charging techniques to reduce environmental pollution and protect the agricultural plant. Pesticide electrostatic applications on apple trees found that the electrostatic sprayer improves the cover rate by 4.3 times. (Zhao et al., 2005) compared between the induction contact charging ways of spray droplets. The conduction charging method showed more charging efficiency than the induction method. (Esehaghbeygi et al., 2010) compared between the pesticide applications by Spray spinning discs with the electrostatic spraying way on Wheat Weeds Control. The charging system improved droplet deposition in the dense canopy. However, the spinning disc device provided better uniformity of spray droplets with a lower water quantity. (Mamidi et al., 2013) developed a knapsack sprayer into an electrostatic sprayer. The study investigates the effect of several parameters, such as spraying pressure, electrode location, and liquid conductivity, on the charging efficiency of spray droplets. The electrostatic device increases the pesticide deposition by 2-3 folds with better spray uniformity on the target surface. (Gan-Mor et al., 2014) developed a XR8001 brass hydraulic nozzle to electrostatic one. The study showed that the charging quantity of spray droplets strongly depends on the air velocity around the nozzle, and the induction electrode voltage. Field tests of the prototype charging sprayer showed that droplet deposition on under surfaces of leaves and the back part of grape clusters was 2 and 5 times, respectively, more than uncharged droplet deposition.

Patel et al., (2015) conducted a study to design and develop an air-assisted charging nozzle for small-scale farms in India. A new air-assisted electrostatic nozzle depended on the induction method to charge the liquid droplets. Only a few kilovolts were enough to charge the droplets to a high level. Results showed that the spray swath width, which affects the target canopy coverage, improved, and the deposition of liquid droplets increased 2-3 folds with the electrostatic application. (Al-Mamury et al., 2015) developed a spraying mini-robot for pesticide applications with electrostatic technique on cotton plants. The developed electrostatic sprayer charges the spray droplets to a high value until 16 mC/kg. It reduces soil contamination to 55%. (Pascuzzi & Cerruto, 2015) evaluated the A “150 RB14” electrostatic sprayer with patented MaxCharge™ nozzles in the vineyard pesticide applications. The electrostatic sprayer increases the droplet deposition by 12.5% on the upper (inner) vineyard layer and only by 50% on the lower (outer) layer. (Yamane & Miyazaki, 2017) developed an agricultural electrostatic sprayer to reduce vegetable production costs by reducing pesticide usage and working hours. A hollow-cone hydraulic nozzle with high liquid flow rates of 1000 to 2600 $ml.min^{-1}$ was used to charge droplets by a ring induction electrode at 4 kV high voltage. The charging efficiency reached -0.30 and -0.45 $mC.kg^{-}1$ for both rates, respectively. Two sprayers were developed in this study as a boom-type electrostatic sprayer for cabbage plant and electrostatic spraying robot for greenhouse melons. Field experiments showed that the boom-type sprayer reduces the pesticide amount by 30% compared to the traditional method. (Yanliang et al., 2017) designed and tested an unmanned aerial vehicle with an electrostatic spraying system. an electrostatic sprayer consists of an induction electrode and (UAV). A hollow metal ball on an extendable bar was used as a semi-conductive crop for deposition experiments. The spray charging system could improve the spray deposition by 13.6% above the sampling metal ball and 32.6% in the middle compared to the non-electrostatic one. The electrostatic spray system has a more concentrated droplet deposition and provides a smaller drift. (Khatawkar, Dhalin, James, et al., 2020) adapted the traditional knapsack mist blower to an electrostatic spraying system. The air-assisted standard nozzle of this sprayer was developed into a self-atomizing hydraulic electrostatic nozzle to charge the droplets sufficiently. The voltage multiplier circuit with a 6 V DC battery and 2500 mA current was used to feed the induction electrode with the high voltage. The developed charging knapsack sprayer provides twice the charging efficacy compared with the commercial electrostatic spray system ESS. (Salcedo et al., 2020) compared between the FEDE pneumatic charging sprayer and the traditional multi-row one in increasing the pesticide amount on vineyard crops. The spray droplets on the electrostatic sprayer were charged by the MaxCharge™ technology until 10 mC/kg charging efficiency. The electrostatic sprayer provided similar or better deposition with 32 % of fully applied volume than the conventional sprayer. Increasing the forward speed of the electrostatic sprayer (charging activated) and multi-row sprayer provided homogeneous and uniform deposition from the lower forward velocity.

Factors Affecting The Deposition Efficacy of Charged Cloud:

Charging spray droplets can improve the deposition operation of spray droplets on plant targets. Unfortunately, the long distance between the electrostatic nozzle and the plant targets can negatively affect the droplet charge value and, thus, the deposition operation. (Laryea & No, 2003) found that the electrostatic spray technique increases the droplet deposition by 1.3–2.3 folds at a 60 cm distance between the charging nozzle and targets. However, no significant difference between the charged and uncharged droplets on deposition efficiency at increasing this distance to 90 cm. Many studies confirmed that spray charged droplets might lose some of their charges during the movement from the electrostatic nozzle to the distant targets(Appah et al., 2019; Khatawkar, Dhalin, James, et al., 2020; Patel et al., 2017; Sasaki et al., 2013).

Many factors can affect the value of the charge-to-mass ratio of sufficiently charged droplets when these droplets move from the electrostatic nozzle to plant target surfaces. According to the study by (Patel, 2016), the electric fields of the earth's atmosphere and the naturally occurring free charge are responsible for the decrease in charge-to-mass ratio when the charged droplets move from the electrostatic nozzle to the target.

The electric charge of the spray droplets can be lost under the effect of evaporation. According to the experimental results summarized by (Shrimpton, 2005) from many previous works, the break up of the evaporating droplets can occur before and not at the Rayleigh Limit. As a result of this droplet breakup, 1 to 5% of the droplet mass is separated from the mother drop, carrying a charge of approximately 15% of that of the parent drops. Figure 12 shows an imaginary drawing of the drop splitting operation at reaching the limit Rayleigh (Langmuir, 2005).

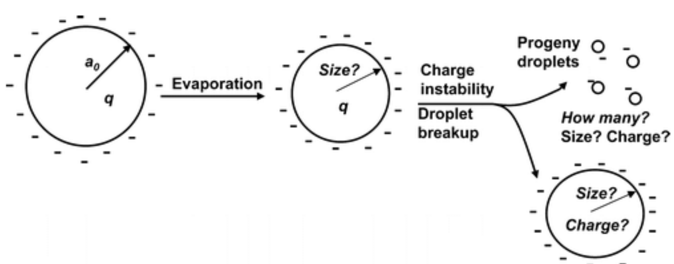

Figure 12: an imaginary drawing of the drop splitting operation at reaching the limit Rayleigh (Langmuir, 2005)

Law (1983) pointed out that the partitioning of mother drop to 2-7 charged smaller droplets with a 5-10 percent original droplet mass may greatly enhance deposition operation on the plant target surface. The study added that the splitting phenomenon did not affect the row-crop applications.

The deposition operation of charged droplets can be affected by the forward speed of the electrostatic sprayer. (Maski & Durairaj, 2010) found that more pesticide deposition on the upper and under leaves was obtained at the medium forward speeds of the machine. However, (Pascuzzi & Cerruto, 2015) noted that the forward velocity of the electrostatic sprayer used for pesticide applications did not affect the droplet deposition of pesticides.

The location of the target leaves inside the agricultural plant significantly affects deposition efficiency since the charged droplets attract to the nearest earthed target surfaces. Therefore, charged droplets may deposit in the outer parts of plants with fewer amounts than in the inner parts. (Pascuzzi & Cerruto, 2015) found that the electrostatic system increases the droplet deposition on the outer parts of the vineyard above the electrostatic sprayer more significantly than the inner parts of the vineyard. Similar results have been obtained in another study conducted by (Kang et al., 2004) about the effect of the electrostatic air-assisted orchard sprayers on droplet deposition. The study noted that the electrostatic sprayer improves pesticide deposition only in the outer parts of the trees. (Inculet et al., 1981) found that the electrostatic orchard sprayer improves the pesticide deposition by 85% in the upper parts of trees compared to the traditional sprayer. However, it did not affect the deposition amount in the underparts of trees.

One factor that increases the efficiency of electrostatic spray use in industrial applications like industrial coating is the good conductivity of the target, characterized as mostly metallic pieces. However, because of the plant targets' low conductivity, the electrostatic spraying technical efficiency in pesticide applications is generally smaller than in the industrial coating. Agri-electrostatic spray can also be applied at different times of the year. During this year, the plants are subject to various changes, including drying out in the seasons with little rain. The little amount of water inside the plant in these seasons causes a decrease in the plant's intercellular liquid that can play an important role in the transport of free charge (by the effect of an electrical field created by the charged cloud) from the earth to the surface of plant leaves. Therefore, for better efficiency of the agricultural electrostatic spray applications, the effect of plant conductivity on the effectiveness of agricultural electrostatic spray must be verified. (Bailey, 1984) explained that if the plant target surface is not conductively well or isolated from the ground, the deposition will occur for only a short period. Then, the target will become fully charged from charged droplets with the same charge signal. Thus, it will start to repel any other droplets trying to enter and deposit inside the canopy. (Lane & Law, 1982) conducted a study aimed to understand the effects of plants' drought stress on the droplet electrostatic deposition efficiency. The study found that electrostatic-deposition techniques can be successfully used on cotton plants without regard to the severity of leaf wilt or drought stress.

The droplet deposition efficiency can be affected by the specific shape of the plant leaves. Plant leaves are grouped into 20 classes based on leaf shape (Hasim et al., 2016). As shown in Figure 13, some leaf classes can have pointed edges like linear, lanceolate, and ovate classes.

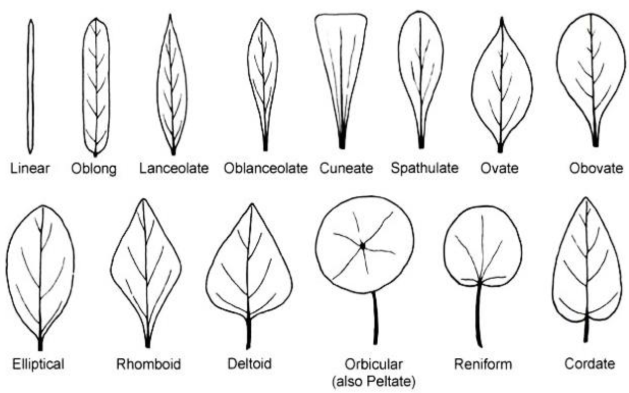

Figure 13: Examples of leaf shapes (Hasim et al., 2016).

The pesticides used for agricultural applications usually have low electrical resistivity values, which do not exceed 102 Ω.m. Unfortunately, some studies confirmed that charging the spray droplets with a high level of electrostatic charge may create discharge currents between the charged cloud and the grounded pointed edges of plant leaves. This unwanted phenomenon can cause a considerable loss of the droplet charge and thus a decrease in the deposition efficiency Figure 14.

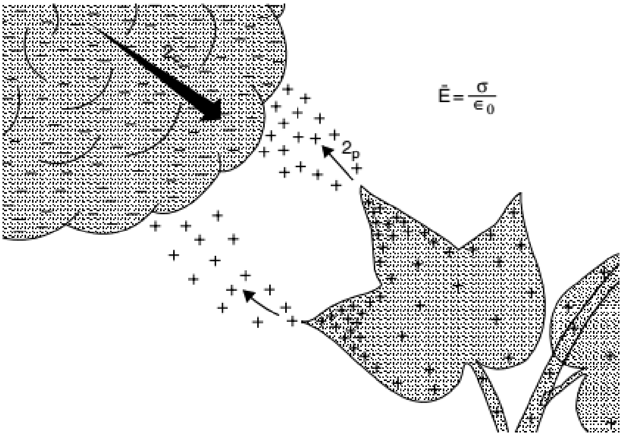

Figure 14 Partial neutralization of charged spray droplets by leaf-tip ionization (S. E. Law, 1980).

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CHAPTER 3

THERMAL ENERGY GAIN FROM THE WASTE HEAT OF AGRICULTURAL TRACTOR ENGINES

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INTRODUCTION

The earth maintains its continuity through the cycle of events taking place in it. In this transformation process, agriculture itself transfers the energy, nutrients and organic materials that it connects with photosynthesis to a higher form. In order for the production to continue in a balanced way, these elements must be included in the system naturally in a long time or in a short time from the outside. The mechanical and electrical energy needed for agricultural activities is insufficient. The energy consumption for tillage in crop production processes is very high. However, the deep tillage and overturning of the soil puts a great strain on the tillage equipment. These reasons necessitate the determination of potential areas where energy savings will be achieved in agricultural production, starting with soil tillage practices for sustainable agricultural production (Soysal and Öztürk 2022). Potential gains in efficiency can be realized by using different energy sources to meet the energy demand for efficiency. In general, regions with high energy consumption have higher agricultural yields. With the ability to do work, energy can be found in this system, kinetic, mechanical potential, chemical, thermal, electrical, magnetic, nuclear, etc. varied in formats. Agricultural production, which is one of the basic requirements for the continuation of life in the modern world, meets the power it needs from different power machines with the development of technology. The energy required to operate these machines is mostly met by petroleum-derived fuels. Due to the increasing concerns about human health and the environment and the pressure on the business economy and costs in agricultural production the against dependence on chemical energy, has increased the search for the use of alternative energy sources such as solar energy, wind energy, hydraulic energy, electrical energy. Today, internal combustion diesel engines are widely used for agricultural production. These engines have the performance to produce work about 30%

of the energy they use. The rest of the energy used is consumed as heat and radiation from the engine. Considering this value as one of the basic parameters that determine the costs on production on a global scale, it is a very important loss and it is important to make the necessary research and investments to use it as an alternative energy source in terms of improving production opportunities. Diesel engines are one of the most used energy-generating mechanisms in agricultural production. About two-thirds of the fuel energy entering the engine is removed by the exhaust gas and cooling water of these engines. In order to get the most benefit from this high-capacity waste heat, a system using energy conversion and conservation techniques should be integrated into the exhaust system. In order to prevent heat loss, the system must be insulated with a durable good material that can provide energy conversion and transfer with minimum loss and high efficiency. Depending on the temperature level of the exhaust stream and the application, different heat exchangers can be used to facilitate the use of the recovered heat. These heat exchangers can be a exchanger that allows the exhaust gas waste heat to pass into the water by passing water through a spirally prepared copper pipe into a circular steel pipe through which the exhaust gas passes. There may be a heat exchanger that transfers the heat of the exhaust gas passing through it to the cold water passing outside by placing several copper pipes inside the circular steel pipe. By arranging a certain number of plates in a row, plate injectors can be used in which the plate directions where the water passes through are narrower, and the plate sides where the exhaust gas will pass are wider.

The tractor, which performs various operations such as tillage, sowing, harvesting, is the most important machine for agriculture. The choice of power in tractors depends on the size of the land and the applications made in the enterprise. Powerful tractors are needed for large land holdings and intensive farm applications. Mowing, plowing and small-capacity transportation can be done with low-power tractors. Powerful tractors can do all the work required in a tasks. They can quickly process large lands using large and heavy equipment. Such tractors are more durable and have a high work capacity. While considering the tractors used to do many jobs in agricultural production, the power to meet the current workload comes to the fore in terms of production. Mechanical energy can be produced to be used in agricultural production by converting the waste heat thrown from the cooling and exhaust systems of the internal combustion engine, which is a power machine that provides the necessary power from the tractors used to do work in agricultural production. Waste heat is generated in a process through fuel combustion or chemical reaction and then discharged into the environment although it has the potential to be reused for economic purpose. The energy lost with the cooling system and waste gases cannot be fully recovered. However, most of the heat can be recovered and losses are minimized. Depending on the temperature level of the exhaust stream and the recommended application, different heat exchangers, heat pipes and combustion equipment can be used to facilitate the use of the recovered heat.

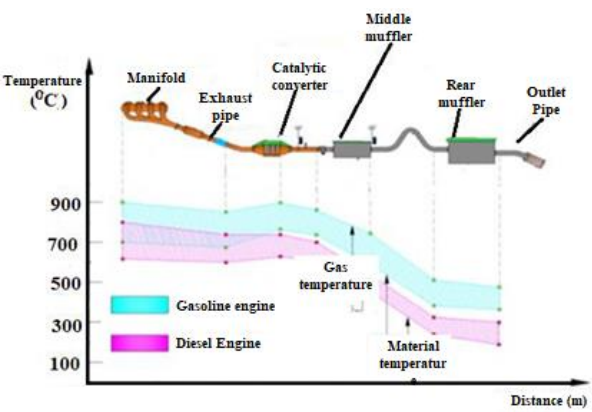

Figure 1. Exhaust gas temperature distributions for Gasoline (upper) and Diesel (lower) engines (Dalar 2019)

This type of waste heat recovery will ultimately reduce the overall energy requirement as well as its impact on global warming. Researchs has focused on the use of sustainable energy sources and energy saving methodologies in consideration of environmental protection and also in the context of great uncertainty over future energy sources. Exergyn reported that heat lost in waste hot water from industrial processes globally is estimated to be about twice that of Saudi Arabia's annual oil and gas production. (Arproget 2022). The CEO of the company, Alan Healy, stated that there is a lot of waste hot water in the world, and in most cases, energy is spent to get rid of waste heat. For example, in cargo ships, water is pumped to cool the engine and hot water is poured into the sea. If a way can be found to contain this wasted energy, both costs and carbon emissions can be reduced. (Isssource 2022).

Heat is a type of energy that occurs due to the temperature difference between the system and its surroundings. All vehicle engines used today are heat engines. The heat released by the combustion of the fuel used is converted into mechanical energy by piston, connecting rod and crankshaft mechanisms. Temperature is a factor that causes the transfer of heat. If the temperature is equal between the system and its surroundings, there is no temperature difference that will affect the heat transfer. Temperature is not a form of energy, it is only a thermodynamic property and can be physically measured.

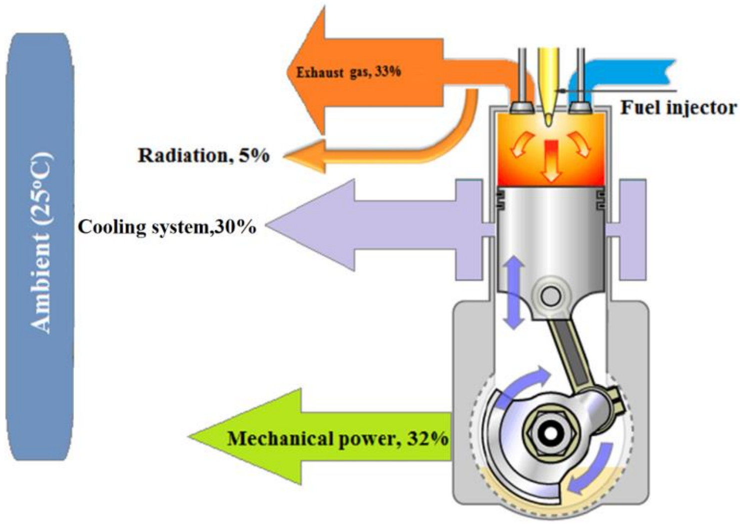

Figure 2. The energy distribution of waste heat sources from a diesel engine (Hoang 2018;Chintala 2018)

The energy calculations of the internal combustion engine, which is a thermal engine, are based on the principle that the total energy supplied to the system is equal to the total energy released from the system, in accordance with the law of conservation of energy. The mass flow of the exhaust gases is calculated by multiplying the actual amount of exhaust gases by the mass flow rate of the fuel injected into the cylinders. The amount of waste heat in the exhaust gas depends on both the temperature and the mass flow rate of the exhaust gas. The internal combustion engine is used as a power source in agricultural enterprises globally. Approximately 1/3 of the total energy given to the thermal engine is emitted from the exhaust system (Morgan et al.,2016; Pandiyarajan et al.,2011; Sayin et al.,2006).

STEAM GENERATION SYSTEM ENERGY CYCLES AND ELEMENTS

OPEN STEAM CYCLE

The feed water, which is under high pressure (exchanger pressure) in the evaporator section of the heat exchanger, is heated from a low temperature (condensate temperature) to the evaporation temperature as isobar (equal pressure) and evaporated. The saturated steam is then superheated by passing it through a second heat exchanger. The temperature of the superheated steam coming out of here is called the fresh steam temperature.

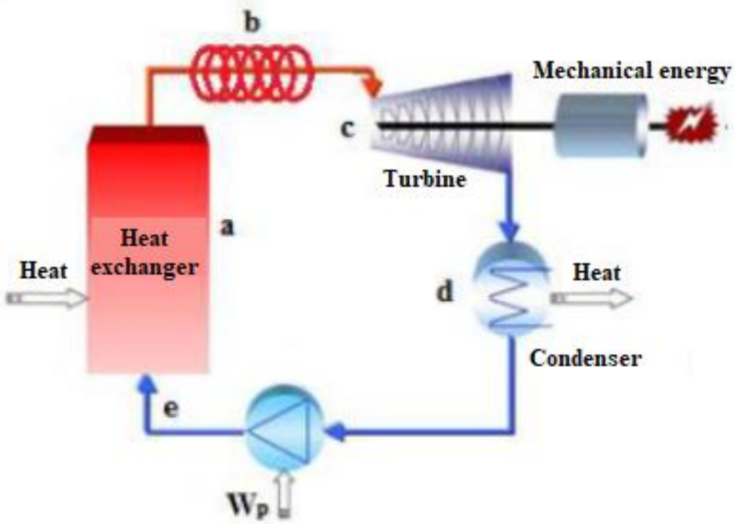

Figure 3. Simple steam power cycle energy cycle

The superheated steam then expands adiabatically (without heat loss) in the turbine to the condenser pressure. During this expansion, the steam temperature drops down to the condensate temperature. The rotten steam coming out of the turbine is condensed in the condenser as isobar and isotherm (at equal temperature). In order to achieve this condensation, the condensation heat of the cooling water and steam must be taken. Finally, the condensate is removed to the heat source pressure adiabatically by the feed water pump. If the friction and heat losses in the pipes are not taken into account, the constant pressure from the feedwater pump outlet to the turbine inlet is called the heat source pressure, and the constant pressure from the turbine outlet to the feedwater pump inlet is called the condenser pressure. The fresh steam temperature remains constant from the superheater outlet to the turbine inlet, and the condensate temperature remains constant from the turbine outlet to the heat source inlet. High pressure is achieved in the feed water pump, and high temperature is achieved in the heat source. This cycle is called the Clausius-Rankine Cycle. (Megep 2014).

STEAM

When water is heated under constant pressure, its temperature rises until it boils. The temperature of the evaporated water remains constant throughout the evaporation. There is a boiling temperature suitable for every pressure. This is called the saturation temperature. For example, the saturation temperature of water at 1 atm pressure is 100 ^{o}C. Steam that does not contain water at its saturation temperature is called saturated steam. If heat is added to the anhydrous heated steam, its temperature rises and becomes super-heated steam. The characteristic of supersaturated steam is indicated by its temperature and pressure. However, a steam at saturation temperature may be dry (anhydrous) or contain a small amount of water. Efforts are made to recover as much as possible the steam used in heating processes, in obtaining mechanical energy, or by directly or indirectly participating in the processes. The recovered, condensed vapors are called condensate. The distribution system consists of valves, fittings, pipes and suitable connections according to the pressure of the transported steam. Steam leaves at the highest pressure demanded by the boilers, process units or power generation. The pressure of the steam is lowered in the turbines that drive the process pumps and compressors (Beşergil 2022).

RANKINE CYCLE

The ideal or theoretical cycle of simple power units is defined by the Rankine cycle shown in Figure 3. The system consists of a heat exchanger, a steam turbine, a condenser and a pump that presses the hot water into the steam boiler.

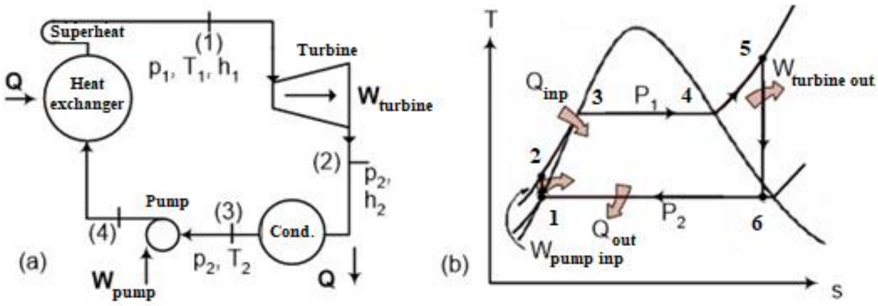

Figure 4. (a) Current diagram of the Rankine cycle, (b) T–S diagram

Energy analysis is based on the principle of conservation of energy, the first law of thermodynamics. From the conservation of energy of the Bernoulli principle equation, the conservation of energy equations are derived from the net effect of the work and heat interactions that take place between the system and the environment. The first law is written for a continuous flow control volume with multiple inlets and outlets;

$$\dot{Q} - \dot{W}_{th} = \sum \dot{m}_ç \left(h_ç + \frac{V_ç^2}{2} + g z_ç \right) - \sum \dot{m}_g \left(h_g + \frac{V_g^2}{2} + g z_g \right)$$

If the heat transfer term is eliminated in the equation and potential and kinetic energy differences are neglected, the power produced in an adiabatic process can be found with the following equation.

$$\dot{W}_{th} = \sum \dot{m}_g h_g - \sum \dot{m}_ç h_ç$$

CLOSED STEAM CYCLE WİTHOUT STEAM TRAP

Conventional steam generation systems have a set of control and trap units. As the steam circulates in the system, losses and leaks occur, which causes the water level to decrease and the pressure to drop. Substances in the additional water given to supplement the reduced water cause corrosion and deposit accumulation in the system. To prevent this, treatment systems and chemicals are used. Since there is no trap in the closed steam cycle, flash steam losses do not occur. The lost energy thrown into nature is used in the system. Optimum process pressure and temperature are regulated. More regular use of steam is provided. The entire temperature of the steam produced in the heat source is included in the process. Since the condensate tank is not needed, the hot water is sent to the heat exchanger. Since it eliminates the use of steam trap, waste and disruption in production are minimized. Since the condensate is sent to the heat exchanger in the superheated water phase, the heat exchanger loads heat as much as the amount of heat used in the process. When condensation forms on the heat transfer surface, it is discharged very quickly without forming a barrier between the steam coil and the product. The steam is circulated faster in the coil and the condensate is drawn out by the recirculating steam. This increases the heat transfer rate by up to 25%. Water does not accumulate in the steam area and the steam pressure is reduced in the separator. The flash eliminates the evacuation of steam. Low pressure steam is reused in the system, eliminating steam loss.

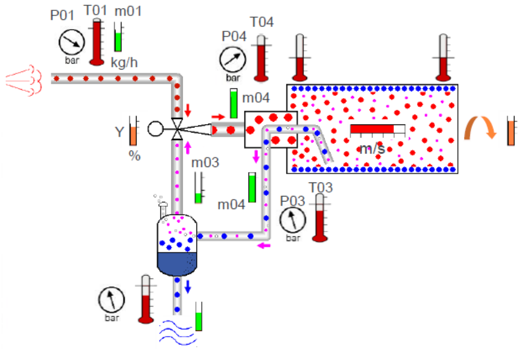

Figure 5. Closed system steam cycle

In conventional systems using steam, a set of steam traps and a 2-way control valve are used to discharge the condensate. During the start of the heating cycle, the condensate is sent to the boiler with a small amount of steam pressure. However, water accumulation occurs frequently and accurate temperature control cannot be achieved. The steam condensation and the steam-condensate mixture at the bottom of the jacket have a velocity of 1-2 m s^{-1}. Therefore, the lower part of the system cannot be heated as well as the upper part, as it leads to lower heat transfer.

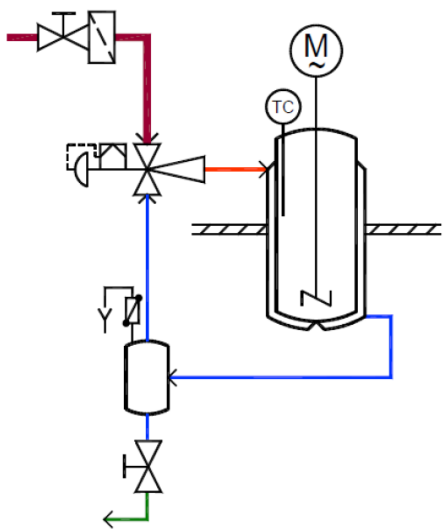

Figure 6. Closed system steam cycle diagram

In the closed system, a higher steam velocity is achieved within the heating surface. Because a certain amount of steam is recirculated. Thanks to this circulation, high efficiency is provided due to equal heating and high heat transfer on the heating surface. Due to the efficient heat transfer in the system, less energy is needed per kg of product. Although the system uses the same amount of steam, it either increases the system efficiency by 40% or can save at this rate, as it gains the flash steam going to the trap.

TURBINE

The thermal turbo machines that convert the thermal energy of a fluid with high thermal energy, that is, high pressure and temperature, into mechanical energy are called turbines. Steam turbines use water vapor as a fluid. The high pressure and temperature steam produced in the heat source rushes into the low pressure and temperature condensate. Because there is no other place to go in the circuit. The turbine is mounted on the road connecting the heat source and the condensate. Thus, in order for the steam produced to go to the condensate, it has to pass through the turbine. There are fixed and mobile wings inside the turbine. The fixed wing reduces the pressure of the steam and sprays it on the mobile wings. The mobile wings takes the kinetic energy from the steam that comes to it and turns it into mechanical energy. The wings create an obstacle in front of the steam. As the steam passes through these obstacles, it loses its energy by giving it to them. Therefore, the pressure and temperature decrease. It turns into water at an average rate of 10-15%. The steam that has lost its energy coming out of the turbine is called rotten (wet) steam. In other words, the heat source creates steam, while the turbine takes the energy of the steam sent by the heat source.

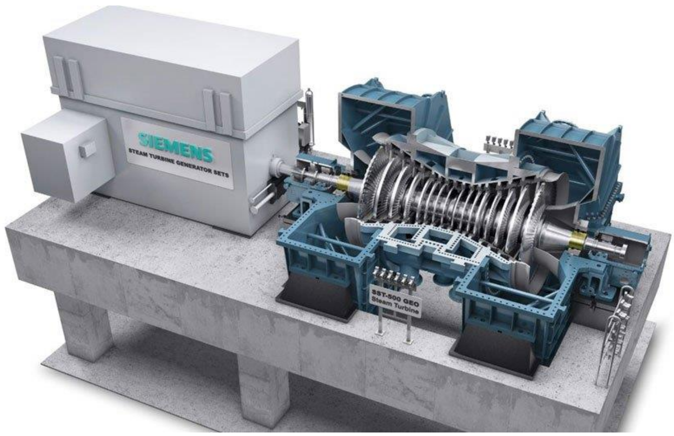

Figure 7. Steam turbine

The heat given to the exhaust gas by combustion is used in a heat exchanger to heat the water to the temperature at which steam is produced. This steam is then passed through a turbine. The energy contained in the steam is extracted by allowing the steam to expand and cool as it passes through the turbine. This energy turns the turbine blades to which a shaft is attached. This shaft is connected to a mechanical unit and produces the torque required by the machine attached with the PTO in the mechanical unit. After passing through the turbine in the open system, the steam passes through a condenser. Here it is cooled and becomes water to re-enter the boiler. Kapalı sistemde buhar türbinden geçtikten sonra tekrar ısı eşanjöründen geçirilerek mekanik iş için kaybedilen ısı kadar enerji kazanarak sisteme girer. The condensed water enters the heat exchanger through the condensation line and is evaporated.

SEPARATOR

Since the vapor storage volumes and evaporation surfaces of the heat exchangers are small, the steam output velocity are very high and the resulting steam is wet. This causes the transport of water droplets to the steam lines along the transmission line, causing problems in the control valves and process lines. The separators reduce calcification on valves and heat transfer surfaces while maximizing the dryness rate of the steam produced. It provides dry steam to the turbine by separating all water particles from the system. Thus, turbine wings and body are protected from abrasion and water hammer damage.

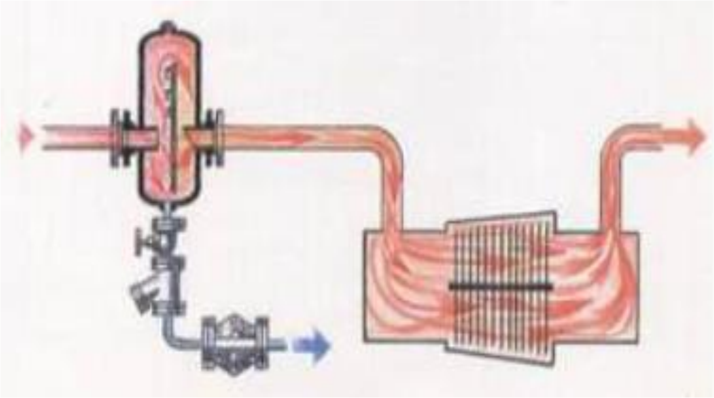

Figure 8. Separator

HEAT EXCHANGER

High-capacity diesel engines are one of the most used power generation units. It is essential to make a serious and concrete effort to protect this energy with waste energy recovery techniques. The heat transfer coefficient (*h*) for gases is usually several times lower than for water, oil and other liquids. To minimize the size and weight of a heat exchanger, the thermal conductivity (h_a) on both sides of the heat exchanger should be approximately the same. Therefore, the heat transfer surface on the gas side must have a much larger area. Heat exchangers need to be more compact as they can practically be realized with circular tubes commonly used in shell and tube heat exchangers. The exhaust gas in an internal combustion engine carries about 32% of the combustion heat (Kumar and Palanisamy 2014). About 50% of the exhaust heat can be used as exergy and is therefore a priority for WHR (Jääskeläinen 2019).

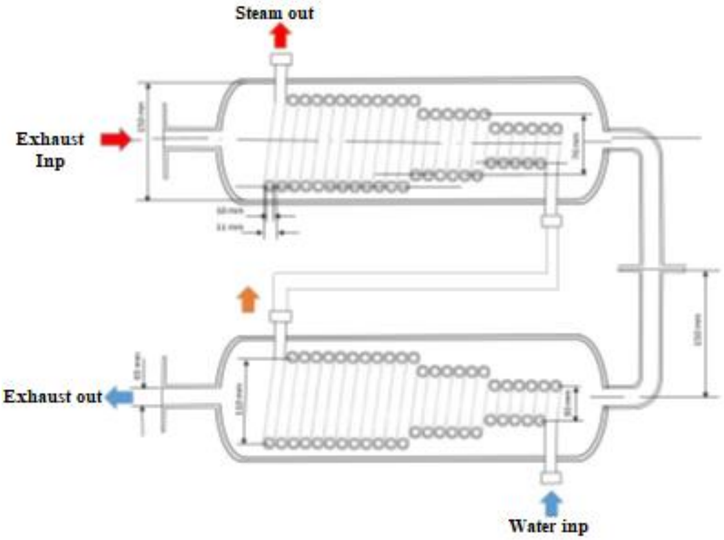

Figure 9. Heat exchanger

The exhaust gas heat released as a result of combustion evaporates the water in the heat exchanger. The magnitude of the temperature gradient between the exhaust gas temperature and the ambient temperature is an important factor for the exhaust heat benefit. The exhaust gases and ambient temperature difference decide the rate at which heat is transferred per unit surface area of the recovery system and the maximum theoretical efficiency of converting heat from the exhaust gases to another form of energy. The temperature range of the exhaust gases has an important function for the selection of waste heat recovery system designs.

CONDENSER

The task of the condenser is to convert the useless steam from the turbine into water in open systems. The condenser both converts the vapors into water and slightly increases the efficiency of the cycle. Inside the condenser are bundles of pipes. Cold water from the cooling tower passes through the pipe. The rotten steam from the turbine passes outside the pipes. As a result of heat exchange, the steam that gives off heat turns into water. It is collected in the chamber under the condenser. The cooling water that receives heat is heated and returned to the cooling tower.

Figure 10. Condenser

PUMP

It sends the condensed water in the condenser to the heat source. Thus, it sends the low pressure water to the high pressure heat source. Steam is called the gaseous state of water. Water, and therefore steam, is a pure substance. Its thermodynamic properties are found from tables or diagrams (Mollier diagram). If two properties are known, other properties can be calculated or determined from diagrams and tables.

REASONS TO USE STEAM

- It is an ideal heat carrier.
- It can carry more heat with small diameter pipes.
- It is environmentally friendly.
- Energy savings can be achieved by recycling.
- The fluid is transported by its own pressure.
- It is possible to perform temperature control very precisely.
- Steam reduces the risk of corrosion in the installation.
- Heat losses are low.
- Thermodynamic properties are good.
- Investment cost is low, small diameter pipes are used, insulation is less.
- It is steam safe, so it does not have flammability.
- It is a sterile fluid.

The disadvantage is; Since it is high energy and pressure, it should be protected.

OBTAINING MECHANICAL ENERGY FROM STEAM TURBINE PLANT

Tractor systems used as power machines in agriculture require thermal form of energy as energy input. There are possibilities to use the heat energy obtained from the tractor engine waste heat with different conversion systems. It would be a more appropriate approach to use these waste heats to generate power to realize the existing work potential instead of throwing them into nature. The heat used in such systems is called process heat. Process heat is generally provided by steam between 5-16 atm pressure and 150-200 ^{o}C temperatures. Fuel in a diesel engine has the following average essential components.

The mass content of diesel fuel is 87% C, 12.6% H and 0.004% O (the amount of sulfur (S) and water vapor (W) is taken as zero). Hu = 42.440 kj kg^{-1}, the lower calorific value of the fuel used and the average stated pressure P_i is 1.203 MPa, the stated efficiency η_i is 0.467.

Tractor power, which can meet all the works needed in regions where agricultural production is intense, is in the range of 50-90 kW. The engine characteristic data for the generation of mechanical energy from the waste heat of a four-stroke, four-cylinder, supercharged (turbocharged) tractor with an average power of 75 kW are given in Table 1. According to Kolchin and Demidov (1984);

Table 1. Engine performance data

Conditions	***Symbol***	***Data***	***Unit***
Piston average speed	$\upsilon_{p.m}$	8.817	ms^{-1}
Mean pressure of mechanical losses	P_m	0.93	MPa
Average effective pressure	P_e	1.01	MPa
Mechanical efficiency	η_m	0.840	-
Heat efficiency	η_e	0.392	-
Effective specific fuel consumption	g_e	216.392	g(kWh)$^{-1}$
Engine capacity	V_l	3.906	L
Engine power nominal	N_e	75.614	kW
Fuel consumption	G_f	16.333	Kgh^{-1}
Total amount of heat supplied to the engine as fuel	Q_o	192547.92	Js^{-1}
The temperature of residual gases	T_r	786	K
Exhaust gas temperature	t_r	513	ºC

Appropriate engine speeds, average pressure of mechanical losses, average effective pressure and mechanical efficiency, heat efficiency, effective specific fuel consumption and cylinder dimensions should be determined for the steam work to be done with the tractor. The operating parameters for determining the economical fuel consumption were determined in the range of 1500-1900 min^{-1} for the engine speeds at which the tractor works the most (Table 1, Table 2).

Table 2. Engine performance values for 1500-1900 min^{-1}

Conditions	***Symbol***	***Data***		***Unit***
		1500 min^{-1}	***1900 min^{-1}***	
Motor power	$N_{e1500-1900}$	58.270	70.026	kW
Effective specific fuel consumption	$g_{e1500-1900}$	208.324	205.629	$g(kW\ h)^{-1}$
Hourly fuel consumption	$G_{f1500-1900}$	12.139	14.447	kgh^{-1}
Total heat supplied to the engine as fuel	$Q_{o1500-1900}$	143105.322	170314.078	Js^{-1}
Heat equivalent to effective work	$Q_{e1500-1900}$	58270	70026	Js^{-1}
Heat transferred to cooling	$Q_{c1500-1900}$	41252.929	53145.093	Js^{-1}
Exhaust heat	$Q_{r1500-1900}$	40841.362	48606.571	Js^{-1}
Total waste heat	$Q_{top1500-1900}$	82094.291	101751.664	Js^{-1}
The amount of water heated	$m_{1500-1900}$	558	653	Lh^{-1}
The water flow through the radiator	$m_{c1500-1900}$	2.035	2.320	Ls^{-1}
Flow rate of water passing through the heat exchanger	$m_{w1500-1900}$	0.205	0.243	Ls^{-1}

Combustion products are determined by the actual combustion equation written for exergy analysis. $C_{17}H_{34}$ is often used as a diesel engine fuel formula. Combustion reaction per unit fuel;

$$C_{17}H_{34} + 43.35(O_2 + 3.76N_2) \rightarrow 17CO_2 + 17H_2O + 163N_2 + 17.85O_2$$

The thermophysical properties of the exhaust gas (Table 3) are determined.

Table 3. The thermophysical properties of the exhaust gas (Toraman 2021)

Conditions	***CO_2***	***H_2O***	***N_2***	***O_2***	***Exhaus***
M kg	44.009	18.15	28.01	15.99	
N kmol	17	17	163	17.85	
Specific heat c_{pr} J(kg K)$^{-1}$	1159	2144.	1122	1049.	1177
Density ρ_r kg m^{-3}	0.6997	0.286	0.445	0.508	0.472
Thermal conductivity k_{Tc} W(mK)$^{-1}$	0.0536	0.068	0.054	0.062	0.055
Dynamic viscosity μ Nm^{-2}	34486x	2889x	3476x	4150x	3475x
Kinematic viscosity υ m^{2}s^{-1}	49246x	10407x	8021x	8388x	7771x
Prandtl number P_r	0.7460	0.911	0.721	0.701	0.733

For steam production, water enters the heat exchanger at 100 °C and is heated up to 200 °C. Thermophysical properties of water at an average of 150 °C are as in Table 4.

Table 4. Thermophysical properties of water at 150 °C

c_p [J(kg	ρ [kgm^{-3}]	k	μ [Nsm^{-2}]	υ [m^{2}s^{-1}]	P_r
4298.915	916.755	0.681	1.814 x	0.2025 x 10^{-6}	1.2336

1- The heat equations for the calculation of the energy given to the steam and the equations used in the study of the Rankine cycle for the four equipment by making use of the Bernoulli equation can be adapted as follows. The amount of heat that must be given until the water reaches its evaporation temperature.

1-3 saturation of water (3 point saturated liquid point).

$$\dot{Q}_1 = \dot{m}c_p(T_2 - T_1)$$

2- There is heat input to the heat exchanger but no work input energy equation.

Since it is a heat exchanger $(\dot{W} = 0)$;

$$\dot{Q}_2 = \dot{m}(h_3 - h_1)$$

$\dot{m}$ (kg s^{-1}) mass flow of water, c_p specific heat at constant pressure (kj kgC^{-1}). h_1 (kj kg^{-1}) enthalpy of water at a temperature below its boiling point, h_3 (kj kg^{-1}) enthalpy of saturated liquid.

3- In case of no heat transfer and work transfer for the pump;

Since it is a pump $(\dot{Q} = 0)$;

$$\dot{W}_{pompa} = \dot{m}(h_2 - h_1)$$

Or by utilizing the pressure difference;

$$\dot{W}_{pompa} = v_1(P_1 - P_2)$$

The v (specific volume) in the equation is found in the saturated liquid $v_1 = v_{f@p_2}$b part in the thermodynamic tables.

4- There is heat input to the heat exchanger, but since there is no work input, the energy equation is. Since it is a heat exchanger $(\dot{W} = 0)$;

$$\dot{Q}_3 = \dot{m}(h_3 - h_4)$$

h_4 (kj kg^{-1}) enthalpy of saturated steam.

It is a mixture of 3-4 saturated liquid-saturated vapor (wet steam). In order to determine the amount of steam in this region, the dryness value x is defined.

$$x = \frac{\dot{m}_{buhar}}{\dot{m}_{buhar} + \dot{m}_{su}}$$

x= dryness value 0<x<1.

5- The amount of heat required to obtain superheated steam from saturated steam.

From 4-5 saturated steam to superheated steam (5 point superheated steam point)

$$\dot{Q}_4 = \dot{m}(h_5 - h_4)$$

h_5 (kj kg^{-1}) enthalpy of superheated steam.

6- Since there is no heat input in the turbine, the energy it produces;

Since the turbine is $(Q = 0)$;

$$\dot{W}_{türbin} = \dot{m}(h_5 - h_6)$$

7- In the condenser, there is heat output to the system, but when there is no work input, the energy equation is as follows $(\dot{W} = 0)$.

$$\dot{Q}_5 = \dot{m}(h_6 - h_1)$$

As with all cycles, the most important characteristic of the simple Rankine cycle is its thermal efficiency. The thermal efficiency is the ratio of the net work in the cycle to the heat input.

$$\eta_{th} = \frac{\dot{W}_{net}}{(\dot{Q} + \dot{W})_{giren}} = 1 - \frac{(\dot{Q} + \dot{W})_{çıkan}}{(\dot{Q} + \dot{W})_{giren}}$$

$$W_{net} = (\dot{Q} + \dot{W})_{giren} - (\dot{Q} + \dot{W})_{çıkan}$$

The specific heat of water is evaluated as 4,186 kj kgC^{-1} independent of pressure and temperature.

Relationship between saturation temperature and saturation pressure;

$$T_s = 100\frac{P_s}{2}$$

T_s (°C) temperature of saturated steam, P_s (bar) is the absolute pressure of the saturated vapor. This equation can be used in the pressure range of 1-220 bar. In practice, 540 kcal (2256,5 kJ kg^{-1}) is required for 1 kg of steam and this value can be used in calculations to determine the capacity.

While the temperature remains constant during the evaporation event, the temperature of the system begins to rise after the last drop of water turns into steam. The heat given off is then used to raise the temperature of the steam. However, since the heating temperature of the water vapor is such a low value as $c_p = 0.4416$ kcal (kg ^oC)$^{-1}$, a small amount of energy is sufficient to raise the temperature of the steam. Therefore, the slope of the curve in the graph becomes steeper. (Beşergil 2022). In this system, a mini steam turbine is connected to the tractor and a double heat exchanger is connected to the engine exhaust system, copper pipelines are drawn to create the connections. Control valves, separators, compressor and pump required for the operation of the system are installed in their places in the system. While the tractor is working in the field, the engine reaches the regime temperature. At different loads and revolutions of the engine, the heat energy emitted from the exhaust is at different levels. Tractors mostly produce work in the field at 1500-2000 min^{-1} revolution. It is stated from the catalog data of a tractor with a nominal power of 75 kW that they produce an average of 65-72 kW of power in these rev ranges. At active operating cycle loads, %30±7 of heat energy is consumed from the exhaust. The value of this energy is about 40-55 kW. The steam changes according to the waste heat it creates according to the operating speed of the engine. The amount of heat released from the engine by the exhaust is determined as 40,841 kW according to the average 1500 min^{-1} cycle in which the engine will operate under field conditions. At 1900 min-^{1} engine speed, the amount of heat released from the exhaust becomes 48,606 kW (Toraman 2021). Currently, there are steam turbine power plants operating with open and closed system cycles. It is stated that the efficiency of these power plants is between 35% and 62%. While the steam turbine system, which is attached to the tractor engine exhaust system, operates at 1500 min^{-1}, 14.25 kW and 24.51 kW power are obtained, respectively, from the steam turbine operating at different cycle efficiencies. The mechanical energy obtained from the steam turbine operating at different cycle efficiencies while operating at 1900 min^{-1} revolutions, respectively, is 17.15 kW and 29.16 kW power. 14,025 kW of the energy consumed by a 75 kW tractor is consumed in the

PTO (Fluck, 1992). The power obtained from the PTO attached to the steam turbine power plant is capable of meeting the needs of different machines while working in the field. By using the PTO obtained from the steam turbine instead of the PTO power produced from the tractor engine, the energy consumed is saved. The saved 14.25 kW and 29.16 kW power are used to operate the tractor. In other words, this tractor with a power of 75 kW gains the ability to carry out agricultural works with a tractor power of approximately 89 kW and 105 kW. Thus, when the power required for agricultural works is saved, it is possible to operate work machines with a larger capacity than the same tractor power. Along with the additional power gained, the power obtained from the tractor engine can be spent as drawbar power. There are 338.625 pto driven sprayers which are used in Türkiye (İtmeç and Bayat 2017). It is difficult to work at high spraying speeds, especially with field sprayers with wide and heavy blades with a large working width (Toraman et al., 2021). According whit while the steam turbine will meet the rotational moment required for the use of a large sprayer from the power produced from the power plant, the power required to pull the sprayer will be more easily realized by adding the power it will consume to the tractor engine in the PTO. Since the PTO power is obtained from waste heat, the working possibilities of different work machines together with the tractor's own PTO power as well as the operation of the existing work machines are increased. In other words, more work is done at once when the tractor enters the field.

40841 Js^{-1}-48.606 Js^{-1}'of the 192547,92 Js^{-1} fuel energy consumed by the tractor engine is saved and brought into production thanks to the equipment installed in the exhaust systems. Thanks to the equipment installed in the exhaust system of the tractor engine, at least 21% to 30% less fuel is consumed from the turbine power plant systems that produce steam. The difference between the selling price of a 75 kW tractor and the selling price of a 105 kW tractor can be an important consideration in terms of the possibilities and savings of installing a waste energy system on a tractor engine, making it a good investment.

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CHAPTER 4

DRIFT REDUCTION TECHNOLOGIES IN PESTICIDE APPLICATIONS

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INTRODUCTION

Despite the continuous increase in the world population, the gradual decrease of arable land for various reasons causes the problem of food supply. It is stated that the sum of crop losses due to diseases, pests and weeds in agricultural production is 35% (Kansu, 1981). For this reason, in order to meet the food requirement of the ever-increasing world population, it is necessary to increase the productivity in agricultural production and to reduce the crop losses due to diseases, pests and weeds to the lowest level as possible. In modern agriculture, crop protection has a very important role in increasing the amount of crop taken from the unit area and increasing the product quality. Crop protection is the protection of plants from the effects of diseases, pests and weeds within economic measures and increasing the product and quality. In order to achieve this aim, crop protection should be carried out in accordance with the concept of Integrated Pest Management (IPM). IPM is defined as the crop protection from the effects of diseases, pests and weeds, and minimizing the negative effects on the environment and human health, by using all known methods in agricultural control as much as possible and in a balanced way (Delen et al., 2005). In the crop protection against diseases, pests and weeds, methods such as cultural, physico-mechanical, genetic, biological, biotechnical and pesticides are used (Toros and Maden, 1991). Within the scope of IPM, these listed methods should be used together and in a balanced way as much as possible, but the most used method in the world is the pesticide application method. The reason for this is that chemical control applied in a conscious and controlled manner has a higher efficiency compared to other methods, gives faster results, and allows plant growth to be directed according to demand (Delen et al., 2010). Despite all these advantages pesticide applied unconsciously and uncontrollably causes environmental pollution and health problems. In addition, it causes a decrease in the sensitivity of harmful organisms to pesticides and adversely affects the export of agricultural products due to excessive residues in the crops (Delen et al., 2005).

The conscious and controlled pesticide application method not only increases the effectiveness of pesticide application, but also reduces the loss of pesticides through drift and run-off, thus minimizing the negative effects on the environment and human health. In addition, the increase in the efficiency of pesticide application reduces the cost of spraying by reducing the number of applications. The most important reasons for unconscious and uncontrolled pesticide administration; These can be listed as wrong selection of the pesticide formulation applied, not spraying at the appropriate time, excessive number of pesticide applications, wrong selection of the equipment used in pesticide application, inability to calibrate the selected equipment correctly, and insufficient experience of the operator. In addition to these listed components, application efficiency can vary considerably depending on the technological levels of the machines used in pesticide applications. Technologies that increase application efficiency can reduce environmental pollution considerably by minimizing pesticide losses through drift and run-off. In this section, it is aimed to give information about the developments in pesticide application techniques and technologies, which increase the effectiveness of pesticide applications and reduce environmental pollution by minimizing pesticide losses.

Pesticide Drift and Factors Affecting Drift

Pesticide drift is defined as the movement of pesticide droplets in the air from the target area to a non-target area during or after spraying. This movement of pesticide droplets in the atmosphere, while remaining within the farm boundaries in some cases, can affect very long distances from the field or farm boundaries under certain conditions (Ozkan, 1995).

Pesticide drift is mostly associated with the physical movement of pesticide droplets away from the target area during spraying. This type of drift, called airborne drift, is due to factors related to pesticide application methods and machinery. Small spraying droplets can travel thousands of meters before settling on target surfaces. Fine droplets in the air can evaporate in the atmosphere and can be carried metres away. Pesticide drift can sometimes occur with the evaporation of pesticide droplets that settle on the target surface after spraying (vapour drift). Vapour drift by evaporation is generally associated with the evaporation property of pesticides (Ozkan, 1998).

Factors that play an important role in spraying drift can be listed as follows: weather conditions during application (wind speed and direction, air temperature, relative humidity and temperature, atmospheric stability and reverse air currents), droplet diameter and droplet spectrum, characteristics of the pesticide formulation such as evaporation and viscosity, spraying height is the operator's knowledge and skill (Dursun, 1998).

Wind speed is the most important factor affecting spraying drift. As the wind speed increases, the amount of pesticide carried out of the target area and the movement distance of these pesticides increase. As a droplet falls through the air, the surface molecules of the water evaporate. This evaporation reduces the size and mass of the droplet and causes it to drift further away from the application site. Low relative humidity and high temperature conditions result in faster evaporation of spraying droplets and higher pesticide drift. Unstable atmospheric conditions also increase drift. After wind speed and direction, the most important factor affecting drift is spraying droplet size. Small droplets fall slowly in the air and are carried farther by air movement.

In addition to the droplet size, the droplets spectrum, that is, the drop lets diameter distribution, is also effective on spraying drift. Some pesticide formulations are very volatile. In spraying with such formulations, the diameters of the droplets formed rapidly decrease due to evaporation and become suitable for drifting. The higher the height of the nozzle from the ground, the higher the wind speed, usually. In addition, with the increase in nozzle height, the distance of the drops to reach the target also increases and thus it is exposed to the drift effect of the wind for a longer time. Also, in a study by İtmec et al., they stated that the downwind drift as spray pattern displacements was significantly reduced in the angled position of the nozzles compared to the non-angle position. They found that the highest downwind drift reductions were obtained with AIXR11002 (38.47%) at 200 kPa pressure, 2 m s-1 wind speed and 15° orientation angle (İtmec et al., 2022).

By making the right decisions regarding both equipment and atmospheric conditions according to the application conditions, the operators can minimize the spraying drift in almost any condition (Dursun, 1998).

Reducing Spray Drift and Improving Application Efficacy

A large number of studies have been carried out by researchers in order to develop new methods and equipment, maximum effectiveness from pesticide application by minimizing the risk potential to the environment and operatör (Dursun et al., 2005). A significant part of these studies focused on increasing the adhesion rate of the applied pesticide on the target surfaces as much as possible and reducing the pesticide losses through drift. Another important issue is the improvement of spray distribution uniformity on target surfaces. For this purpose, studies are carried out on the design of the spray system according to the geometric dimensions and canopy shapes of the target plants and the use of different application techniques. In recent years, studies on precision pesticide applications have increased considerably. The purpose of these studies is to administer pesticides only to the target areas and not to the non-target areas. In addition, it is the change of the amount of sprayed pesticide according to the characteristic feature of the target. Some studies are for easy, effective and safe use of application equipment. Detailed explanations of important developments in pesticide application technologies are given below.

Low Drift Nozzles

The selection of the sprayed pesticide in pulverization is a very complex process. An ideal pesticide should be sufficiently effective against target pests, have as few side effects as possible, and have no adverse effects on humans and other beneficial organisms (Matthews, 1984). In order for the pesticide to be sufficiently effective on the target pests, it must be sprayed with droplets of the appropriate droplet size. Within certain limits, small droplets provide a more uniform coverage. However, if small diameter droplets (<100 µm) are not deposited on the target with a good technique, they cause pestide losses by being carried out of the target or evaporated (<50 µm) due to their small mass (Zhu et al., 1994). The phenomenon of transporting the pesticide out of the targeted area and surfaces is called Drift. On the other hand, large droplets (>200 µm) are carried to shorter distances by the wind effect and evaporation loss is less. However, large droplets can damage the leaves of the plant, especially in pesticides used with high concentrations. In addition, large drops create a lower coverage on the plant leaves, and sometimes large droplets cannot hold on to the leaves and flow to the ground. Applications made with large diameter droplets cause less pesticide than applications made with small-diameter droplets, while in practice, the biological efficiency of small-diameter droplets is higher. Almost all of the nozzle manufacturers in the world have produced new nozzle types that they call “Low-Drift” nozzles in recent years (Figure 1).

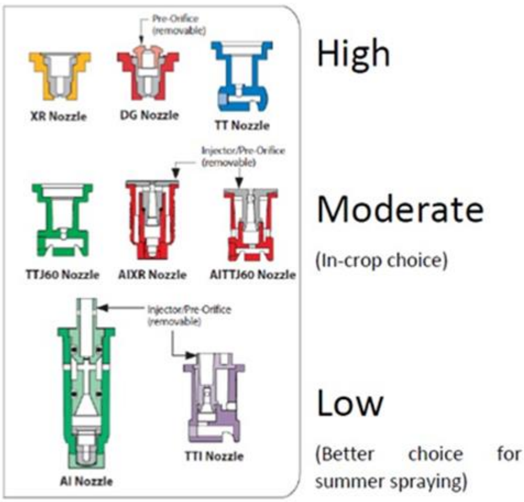

Figure 1. Cross section of TeeJet® nozzles with high, medium and low propensity for spray drift (Anonymous, 2022a)

These nozzles give the same output as standard type flat fan nozzles and produce larger diameter droplets at operating pressure. With this type of nozzle, the number of droplets smaller than 200 µm can be reduced by 50 - 80%. Thus, they form drops that tend to drift less than standard flat fan nozzles of the same size. These nozzles usually have a pre orifice, and the fluid passes through this pre orifice, reducing its velocity and leaving the main outlet orifice in larger drops. In nozzles other than Drift Guard and Turbo TeeJet, the air sucked in through a hole on the nozzle body and the liquid mix with each other and air bubble droplets form when the liquid comes out of the nozzle tip. The air in the droplets increases the droplets size to some extent and provides an increase in the droplets speed (Dursun, 2002).

Air Assisted Spraying Technique

In this type of sprayers, the droplets produced by the nozzles are carried to the target surfaces by the air flow, and the speed and energy gained to the drop is considerably higher than that of conventional sprayers. Thus, the risk of drifting by the wind decreases, the efficiency of the droplets collecting on the target surfaces increases with the additional transport energy provided to the drop, the penetration towards the inner parts of the plant increases, allowing spraying with small-diameter drops (Hislop et al., 1995; Cooke et al., 1990; Dursun, 2002). Since the drift effect of the wind is reduced and it can be operated even at higher wind speeds than conventional sprayers, the number of days that can be sprayed increases (Hadar, 1991). In Figure 2, air assisted boom sprayer and air assited horticulture sprayer are given.

a

b

Figure 2. Air assisted crop (a) and orchard (b) sprayers

Heilsbronn and Anderson (1991) stated in their study that the pesticide loss in conventional applications is twice as high as in air assisted application, and that airflow velocity and direction have a significant effect on reducing pesticide losses. May (1991) tested two different air assisted boom sprayers on sugar beet. He stated that both sprayers reduced the pesticide drift by approximately 50%. Watson and Wolf (1985), on the other hand, reported that with the air assisted application, they achieved a 100% residue increase in corn and 234% in soybean compared to the classical application.

Electrostatic Spraying of Pesticides

In this technique, liquid spray droplets are charged with static electricity and an opposite charge is created on the plant as the charged droplets approach the plant. This opposite (counter) charge is caused by the flow of some electrons from the plant to the soil. Thus, an electrostatic attraction force is created between the drops and the plant surfaces and the charged droplets are deposited on the plant surfaces (Law and Lane, 1982). In Fig. 3, the field sprayer with electrostatic charge is presented. Three different loading methods, namely corona, contact and induction, are used for electrostatic charging of liquid pesticides (Law, 1978; Marchant et al., 1985; Hussain and Kleisinger, 1992).

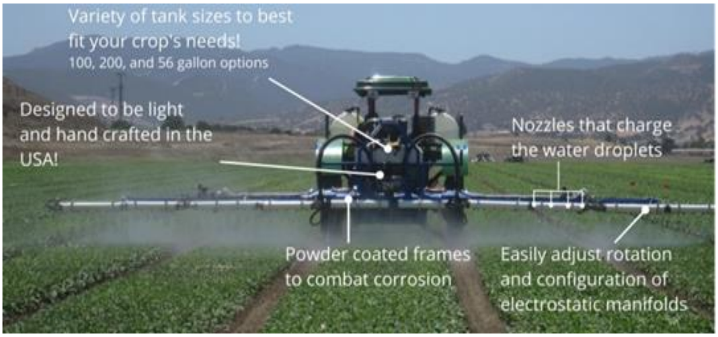

Figure 3. Electrostatic charging boom sprayer (Anonymous, 2022b)

Shielded Sprayers

These arrangements are usually in the form of mechanical protective shielded, either completely covering the spray bar, placed at a certain angle to the vertical in front of or behind the spray bar, or in the form of protective umbrellas placed separately on each nozzle. In Figure 4, an on-row mechanical protective system is given. This type of shielding systems can reduce the drift effect of the wind, ensure effective spraying even at wind speeds that are too high to be sprayed with conventional sprayers, and increase the number of days that can be sprayed. Smith et al. (1982) reported that mechanical protective curtains reduce wind-blown pesticide residues by 70.7%. Ozkan et al. (1997) investigated the effects of 9 different mechanical type shielding designs on the amount of pesticide residues entrained by the wind in their study in a wind tunnel. In conclusion, they reported that the double-deck design reduced wind-entrained debris by as much as 59% compared to the unshielded condition.

Figure 4. Shielded spray boom

Tunnel Sprayer

Tunnel type sprayers have a closed roof to cover the sprayed tree or vine row (Figure 5). Some types have conventional spray systems, some have air assisted spraying. Some models have a reversible system (Ozkan and Fox, 1998). In these types, some of the sprayed pesticide can cross the plant canopy and hit the walls of the tunnel to be collected, and from there it is returned to the pesticide store. In the studies carried out with this type of tunnel sprayer; For example, 40% pesticide recovery was achieved in blackberry and 30% pesticide recovery in sweet corn (Beasley et al., 1983). Recycling systems allow the bulk of the pesticide that does not settle on the target surface to be collected and used later, while also reducing drag. Compared to a conventional sprayer, it can provide 85% reduction in pesticide to the soil surface. While the amount of pesticide that is carried to a distance of 4 m from the last sprayed row is 1% of the dose applied in the tunnel sprayer, this rate is 8% in the conventional sprayer (Huijsmans et al., 1993).

Figure 5. Tunnel sprayer

Spraying Systems Sensing the Plant Canopy

In modern orchards, quite wide spaces are left between the trees on the row. In addition, the canopy structure of new trees planted in place of trees that have dried for any reason is smaller in volume, thus increasing the space between the canopies. These empty spaces form the base zones for drift and pesticide losses in conventional applications. For this reason, various companies producing sprayers have developed sensors that detect the plant canopy for the last 10 years. These sensors, located in the target detection system, distinguish the area where the tree is located and where it is not. When the sensors detect the target, they allow the nozzles to spray, otherwise they close the nozzles. Since the pesticide is not sprayed in the absence of the target, that is, in the cavities, the pesticide application is limited only to the region that includes the targets (Figure. 6).

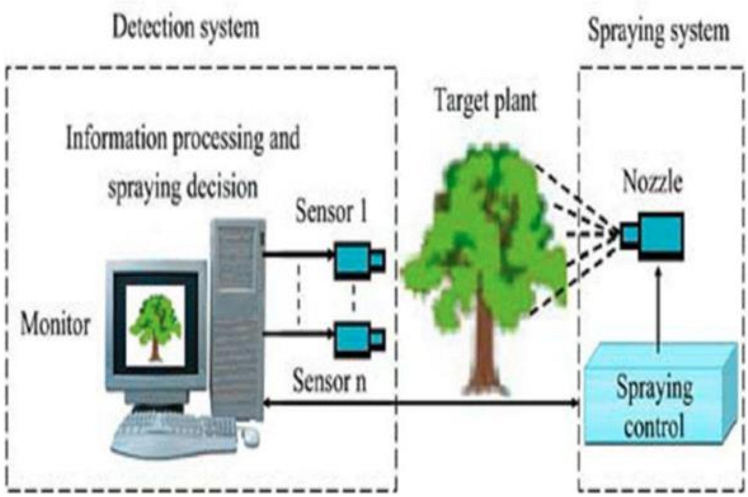

Figure 6. Targeted spraying system based on sensing technology (Hong et, al. 2012).

Many advanced techniques are used to determine the target. Some of those; laser scanning, ultrasonic sensors and spectral systems. Laser technique (LIDAR-light detection and tree gap scanning system) is able to dimension the tree canopy. In this way, it is also possible to adjust via Ultrasonic sensors which can determine whether vegetation is present or not. However, since the scanning area of the sensors is large, it is not possible to identify small gaps (Balsari and Tamagnone, 1998). Spectral systems operating according to the optical reflection principle can determine both the target and target characteristics and vegetation type. Since the beams absorbed by the sensor are very narrow, they can detect even small gaps (Doruchowski et al., 1998). In the system given in Figure 6, the height of the trees and the distance between the trees are detected by the ultrasonic sensors placed in the front of the sprayer, and the spray nozzles located at the back of the sprayer are opened and closed according to the outputs obtained from these sensors. The nozzles are controlled by the computer in the system according to the tree height, the distance between the trees and the speed of the sprayer. According to the recent results (Balsari and Tamagnone, 1997), the system can be used successfully and the amount of pesticide applied has been reduced by 10-35%.

Variable Rate Herbicide Application

The crop and weed can be distinguished from each other by making use of the difference in light reflectance values at certain wavelengths of the crop grown with the weed in the field. Thus, weed control can be achieved by applying herbicides at varying rates according to the weed density in different parts of the field. In Figure 7, a system that detects weed and sprays is shown schematically. Here, an optical-based system was used to separate weeds from the crop and soil. The system consists of a weed-detecting sensor, electronic valve, microprocessor and spray system. The sensor detects the weed and sends a signal to the microprocessor. The microprocessor decides whether there is weed according to the obtained signal, and when it decides that there is weed, it sends an electrical signal to a solenoid valve, allowing the valve to open and spray the herbicide. In this system, each nozzle is equipped with a weed detection system and an on/off valve. As a result of the trials; Compared to conventional spraying, it has been observed that the amount of sprayed area is reduced by 90% and weeds are inactivated by 95% (Felton et al., 1991).

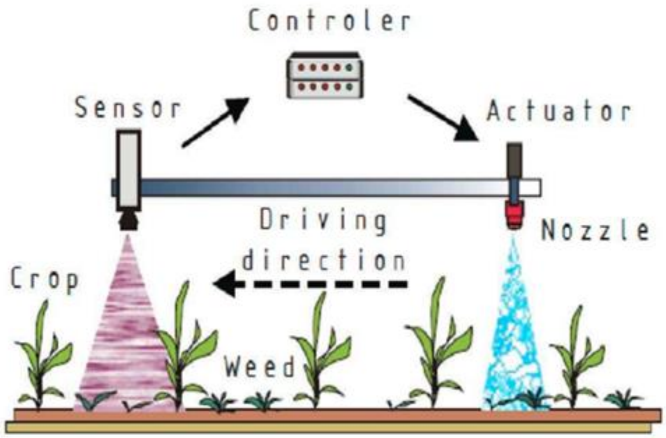

Figure 7. Targeted spraying system based on sensing technology (Hloben et al., 2007)

Özlüoymak et al. (2019) have developed a machine vision-based automatic spraying robot for the detection, monitoring and spraying of artificial weeds using the LabVIEW programming language. They reported that, site-specific spraying application saved on average 89.48%, 79.98%, and 73.93% application volumes for 500 ms, 1000 ms, and 1500 ms spraying durations, respectively, at all spraying speeds is compared to broadcast spraying application.

Measures that can be taken to Reduce Spraying Drift

- To minimize spraying drift, the following should be considered:
- Using nozzles that produce larger droplets in applications that do not require small droplet and uniform droplet coverage (for example, systemic herbicides),
- Keeping the spraying boom height as low as possible,

- Not to reduce the spraying volume and to use nozzles with a large orifice,
- Making applications at low spraying pressure and ensuring the accuracy of pressure gauges,
- Using nozzles that can be operated at low spraying pressures and are known as “low drift nozzles”.
- Using additives and chemicals that increase the viscosity of spraying mixture,
- Using adjuvants and chemicals that increase the viscosity of the formulation mixture (İtmeç et al., 2022)
- Considering the label recommendations to avoid drift in applications with volatile pesticides,
- Avoiding spraying when atmospheric conditions are not suitable. Not spraying if the wind speed is higher than 8 km/h, the weather is extremely hot and/or the relative humidity is too low,
- Not spraying when the wind is blowing towards sensitive products, areas where people live, farm animals and water resources near the sprayed area,
- Using sprayers with fully or partially shielded sprayers boom in field spraying,
- To use air assisted and electrostatic charging application techniques,
- Using new technologies capable of variable rate application.
- Any of the aforementioned factors may be the most critical factor in reducing drift in a given spraying condition. Here, the spraying operator can determine this critical factor and take the necessary precautions against drift. By making the right decisions regarding both equipment and atmospheric conditions according to the application conditions, operators can minimize drift in almost any condition.

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CHAPTER 5

ENVIRONMENTAL EFFECTS OF PESTICIDES

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INTRODUCTION

In the face of the rapidly increasing world population, insufficient food supply is a serious problem. For this reason, it is necessary to increase the production and efficiency of food supply and to take measures to prevent food losses. In order to increase agricultural productivity, it has become necessary to combat diseases, pests and weeds that cause significant losses in agricultural products. It is reported that the loss of agricultural products (due to diseases, pests, weeds, etc.) that may occur if pests are not controlled in the world is at the level of 35% (Yağcıoğlu, 1993). For this reason, in order to obtain disease-free and quality agricultural products, it becomes necessary to struggle against diseases, pests and weeds.

In today's modern agriculture, pest control is considered within the concept of Integrated Pest Management (IPM). Integrated Pest Management as a concept; It is the use of various crop protection methods together, in a way that complements each other and does not disturb the natural balance in the ecosystem, in order to obtain sufficient, quality and economical crop products. The methods to be considered within the concept of Integrated Pest Management (IPM) can be listed as follows (Zeren and Bayat, 1995):

- Breeding new varieties resistant to diseases and pests and spreading the use of these varieties in production,
- Applying appropriate cultural measures,
- Taking advantage of the biological control method and supporting this method in the areas where it can be applied
- Making use of physical pest control methods and trying to develop these methods further,
- It is to take advantage of the chemical pest control method.

Among these methods, the last method to be applied is the chemical pest control method. When diseases, pests and weeds cannot be controlled by other methods, chemical pest control method should be applied. Crop protection products are used in chemical control that are called pesticides. Pesticide is a physical mixture containing an active substance with biological activity and some auxiliary substances, which kills or inhibits their development by acting in various ways on diseases, pests and weeds. Within the scope of IPM, these listed methods should be used together and in a balanced way as much as possible, but chemical pest control method is the most used method in the world. The reason for this is that chemical pest control applied consciously and in a controlled way is more effective than other methods, gives faster results and can provide the desired direction of plant growth (Delen et al., 2010). Despite all these advantages, chemical control, applied unconsciously and uncontrollably, causes environmental pollution and health problems, as well as a decrease in sensitivity to pesticides in harmful organisms and a negative impact on agricultural product exports due to excessive residues in the products (Delen et al., 2005).

Environmental Cycling In Pesticides

Application of pesticide in soil can lead to various fates depending upon its persistence and mobility (Kerle et al., 2007). Figures 1 and 2 demonstrate how pesticides enter the environment through application drift, soil erosion, and dry deposition. (Cessna et al., 2005, 2006). Pesticides are classified into four major classes based on their environmental persistence: organochlorine insecticides, organophosphate insecticides, triazine herbicides, and acetanilide herbicides. (Toth and Buhler, 2009).

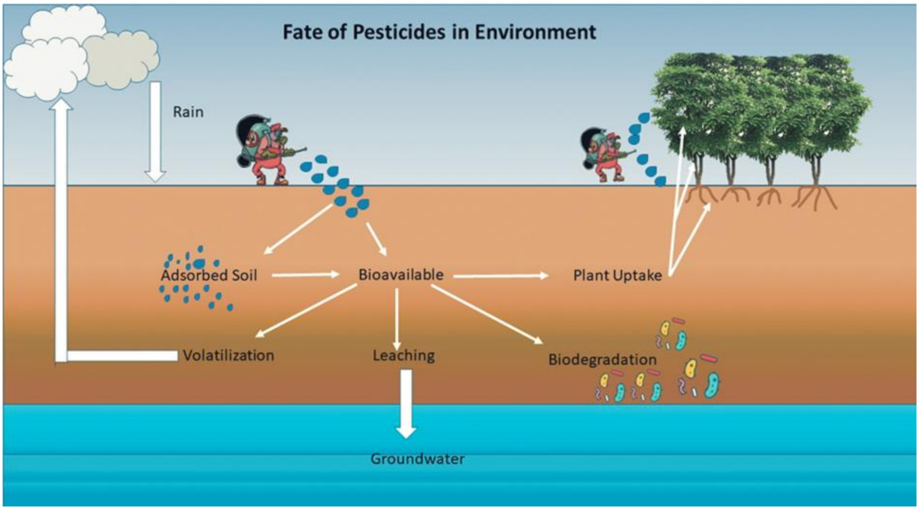

Figure 1. Fate of pesticides in environment (Mehmood Et Al. 2022).

Pesticide entry into aquatic, soil, and atmosphere are the primary pesticide sinks in the environment. (Tiryaki and Temur, 2010). Pesticides fate involves absorption by plants. (Hwang et al., 2017). The second fate of pesticides is adsorption on soil constituents, which is determined by the physicochemical properties of the soil. (Kah and Brown, 2006). Other fates involving pesticide solubilization in soil solution, wind, and soil erosion include pesticide leaching and runoff (Kellogg et al., 2002). Pesticide degradation is a major concern nowadays, and its success is dependent on the physicochemical properties of the media and the nature of the pesticide (Kah et al., 2007). Pesticide degradation is aided by the soil microbial community (Pal et al., 2006). If these pesticides are not degraded in the soil, they can leach out and pollute groundwater (Arias-Estévez et al., 2008) or cause runoff from fields to pollute water (Kellogg et al., 2002). Pesticide activity and bioavailability in soil are affected by a variety of factors, including soil pH (Kah et al., 2007), plant growth, and pesticide adsorption in soil (Edwards, 1975).

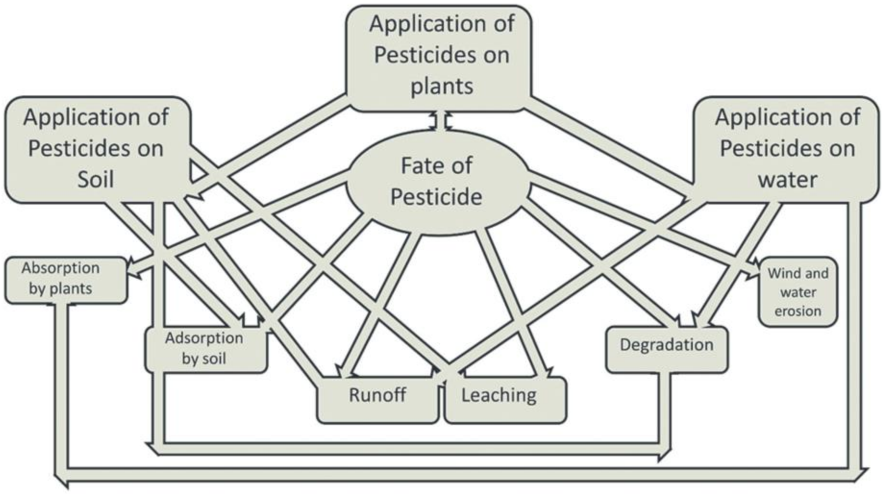

Figure 2. Pesticide application in agriculture, its fate, and bioavailability (Mehmood Et Al. 2022).

Many things happen to pesticides when they are released into the environment. Weed control can sometimes be improved by leaching some herbicides into the root zone. Pesticides can sometimes be harmful to the environment because not all of the applied chemical reaches the target site. (Figure 3) (Cesna2009).

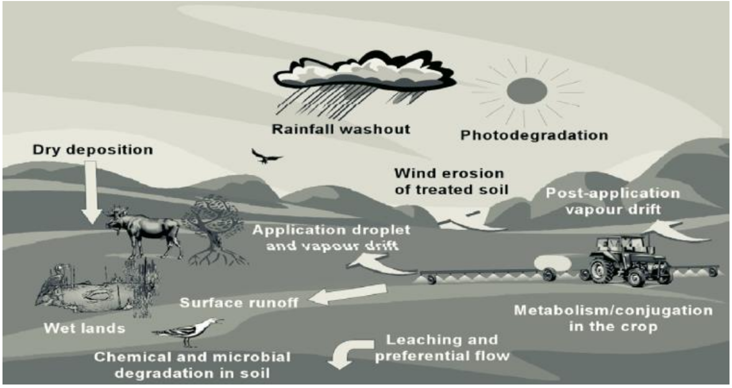

Figure 3. Routes of entry of pesticides into the atmosphere and into Surface and ground waters and mechanisms of pesticide transformation in air, soil and plants (Cessna 2009).

Pesticide properties (water solubility, adsorption to soil, and pesticide persistence) and soil properties (clay, sand, and organic matter) are critical in determining the fate of chemicals in the environment. Environmentalists, scientists, and agriculturalists are all too aware of pesticides' long-term effects as they seep into streams and water courses. Pesticides may contaminate the air in field margins due to application drift, post-application vapour loss, and wind erosion of treated soil. Pesticide deposition in the atmosphere, as well as surface runoff from pesticide-treated agricultural land, can contaminate soil, vegetation, and water bodies near field margins (Tiryaki and Temur, 2010). Pesticide movement from application sites to nontarget areas causes three issues. It represents a financial loss for farmers, ineffective pest control, and potential environmental contamination (Waite et al. 2002).

Environmental Effects of Pesticides

Combine pesticide use with other technologies, such as improved plant varieties and agricultural equipment, to promote the green revolution and the highest capacity for food and fiber production in history. The potential effects on public health and the environment have evolved as the use of pesticides has increased. The environmental impact of pesticide use may also be greater than recommended, due to accidental spillage or long-term in situ soil residence. Pesticide application practices have exacerbated a variety of environmental issues, including human and animal health risks Foods that are contaminated with toxic pesticides have serious effects on human health as they are a prerequisite for life. Pesticide contamination of soil, water, and plants is well known. Pesticides, in addition to killing insects and weeds, can be toxic to a variety of other organisms, including birds, fish, beneficial and nontarget plants. Although insecticides are typically the most toxic type of pesticide, herbicides can also be harmful to nontarget organisms (Mehmood et al. 2022).

Pesticides have an impact on the environment through both point-source and nonpoint-source pollution. The former is contamination that originates in a specific and identifiable location, such as pesticide spills, wash water from cleanup sites, leaks from storage sites, and improper pesticide and container disposal. The latter is contamination from a wide range of sources, such as pesticide drift through the air, pesticide runoff into waterways, and pesticide movement into ground water (Toth and Buhler 2009)

Pesticide-sensitive areas include (I) areas where ground water is near the surface, (II) areas near surface waters, (III) areas heavily populated with people, (IV) areas populated with livestock and pets, (V) areas near the habitats of endangered species and other wildlife, (VI) areas near honey bees, and (VII) areas near food crops and ornamental plants (Toth and Buhler 2009).

Environmental Impact of Pesticides in Soil

Pesticides are an important component of many agricultural management systems, and their effects and ability to destroy soil health should be considered. There is little information available on standard test protocols for determining lethal or sublethal toxicity in pesticide-contaminated soils. The impact of pesticides on one or more indicator species on the health of soil ecosystems is more complicated. This assessment takes into account factors such as soil resilience to harsh conditions, pesticide persistence, and indirect effects. Many pesticides degrade quickly. Others can build up and become more concentrated in the soil when reused (Brasil et al., 2018). Soil fauna (e.g., ticks, nematodes, micro-arthropods, protozoa) plays an important role in organic matter transformation and soil structure, and they are useful biological indicators for studying soil toxicity. Pesticide toxicity to soil fauna and flora is a component of the standardized ecotoxicity test for pesticide registration. The metabolic capacity of soil is typically defined by measuring the activity of various hydrolysis and oxidoreductases. Pesticides have a significant impact on soil enzyme activity. Soil enzyme activity is a useful indicator of soil health and was used to determine whether the negative effects of farming practices affect soil biochemical functions. Pesticides' effect on enzyme activity is determined by soil conditions and pesticide application rate (Haung et al., 2019).

Environmental Impact of Pesticides on Plants

Pesticides not only kill invading pests, but they also have negative effects on the environment, including plants and beneficial microbial communities. Physicochemical behavior, formulation, droplet size, and application technique, precipitation or rainfall and relative humidity, temperature, sunlight, plant species and physicochemical differences, such as stomata, upper/lower leaf surface, hairs, waxes, and time of application during the vegetative period, are all factors that influence pesticide leaf uptake and metabolism. Similarly, physicochemical behavior, application method and amount, physicochemical and biochemical reactions in the soil, climatic factors, and plant development all influence root uptake and degradation of pesticides in soil. The water solubility of the pesticide influences plant uptake in part. Pesticide uptake by plants prevents runoff or leaching (Kerle et al. 2007).

Groundwater contamination by pesticidess is an emerging issue globally. According to the US Geological Survey, at least 143 different pesticides and 21 transformation products have been found in groundwater, including pesticides in each of the major chemical categories (Kim et al., 2017). Plants are susceptible to the indirect effects of pesticidess use when soil microbes and beneficial organisms are harmed. In arctic environmental samples such as Dacthal, Chlorthalonil, Chlorpyrifos, Metolachlor, Terbufos, and Trifluralin, including a new generation of pesticides have been detected. Once the groundwater is contaminated with toxic chemicals, it may take many years for the contaminants to dissolve or be eliminated. Cleaning can also be very expensive and complicated, which is not impossible (Mehmood et al. 2022).

Negative effects of pesticide use on human health

Pesticides are credited with increasing food as well as other features; however, they have a negative impact on human life. Pesticides can cause a variety of diseases in humans. Toxicity can occur as a result of ingestion, inhalation, or dermal absorption (Fantke and Jolliet, 2016). Their ongoing toxicity causes a variety of diseases such as neurological disorders, hormonal imbalances, immune system dysfunction, cancer, blood disorders, genotoxicity, and reproductive system defects (Li and Jennings, 2017). Farmers and farm workers who work with pesticides, including preparing formulation, sprayer operators, mixers and loaders, are at high risk. There is a high probability of danger during the manufacturing and formulation process. Workers in industrial settings are more likely to come into contact with a wide range of toxic chemicals, including pesticides, raw materials, toxic solvents, and inert carriers. Early health examinations, such as liver function, immune function, nerve damage, and reproductive effects, produced astounding results. Excessive mortality from heart and respiratory diseases may be linked to the accident's psychosocial value and chemical infections. Diabetes cases were also on the rise. Follow-up cancer incidence and mortality data revealed an increase in the number of cancers in the gastric, lymphatic, and hematopoietic tissues (Matthews, 2016).

Guide to Reducing the Environmental Risks of Pesticide Applications

Pesticides have the potential to harm the environment if not used properly. It can also keep groundwater free of contaminants, protect the health of your family, neighbours, and livestock, and ensure a clean, healthy environment by:

- Practicing IPM,
- Only using pesticides labeled for the intended crop and pest,

- Taking into account application site characteristics(soil texture, slope),
- Taking into account the location of wells, ponds, and other water bodies measuring accurately,
- Maintaining and calibrating application equipment accurately,
- Carefully mixing and loading,
- Preventing back siphoning and spills, I storing pesticides safely and securely,
- Disposing of wastes safely,
- Leaving buffer zones around sensitive areas,
- Reducing off-target drift using adjuvants and surfactants (Toraman and Bayat, 2019, Itmec et al. 2022)
- Reducing off-target drift using drift reduction technologies (Reichenberger et al. 2007, Cessna et al. 2005).

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CHAPTER 6

DIGITAL AGRICULTURE

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INTRODUCTION

Promoting the productivity and quality of cultivated crops is important for the modern agriculture (İtmeç et al., 2022). Agricultural production is under heavy pressure based upon increasing world population and significant changes in the climate. New developments such as computer and communication technologies require producers to use new generation farming models instead of traditional farming methods in order to increase profitability and preserve sustainability in agriculture. Especially, in last decades, the agricultural sector has been following technological developments with the developments in communication technologies (Ozdogan et al., 2017). Digital agriculture is often used to describe different the use of data collected by different types of technology used in the sector. However, it is also about how this technology integrates and works across the supply chain, all the way from the paddock to the consumer. Digital agriculture can help with the day-to-day management of farms and improve traceability, security and automation. It includes monitoring animals, prescriptive fertiliser programs and geospatial mapping (Anonymous, 2022a).

Agriculture technology has been changing and progressing towards becoming a knowledge-intensive enterprise. Traditional systems have been changing into modern, productive and innovative systems (Andrade-Sanchez and Heun, 2010). Optimization, high precision, real-time and customized information usage processes could be possible with the digital agricultural tools used in all agricultural and livestock systems (Deichmann et al., 2016).

Emergence of precision agriculture implementations has appeared with the developments in satellite, GPS (Global Positioning System), GIS (Geographic Information System) and other mobile communication technologies (López-Riquelme et al., 2016). Especially in recent years, developments such as artificial intelligence, robotic technologies, and big data analysis have combined with other developments in communication technologies such as cloud computing and internet of things allows starting the fourth revolution, namely digital agriculture, for the agricultural sector (Dong et al., 2013; Tan, 2016).

Three main components cause the digital revolution in agriculture. First of all; sensors, which enable the producers in order to track the crops and environmental factors more closely, should be sensitive and affordable. Data on variables such as temperature, rainfall, humidity, wind speed, livestock tracking, plant and animal health is collected by using remote sensors located on farms. The Internet of Things (IoT) describes the network combined with sensors, software and other technologies. Smart farming is the evolution of precision agriculture, it is based on Internet of Things (IoT), this term was coined by Kevin Ashton in 1999 and it represents data collected from objects or 'things', (e.g., devices, implements, sensors) and processed individually or together with algorithms that correlate the information to help the users to take decisions not based only on position, as is in precision agriculture, but also on data 'enhanced by context and situation awareness, triggered by real-time events' (Castrignanò et al., 2020). Secondly, information technologies and applications should be used by producers to keep in touch with each other and with suppliers. And the use of artificial intelligence is more important than the other technologies for increasing productivity and making smart decisions on time. Real-time information data from the field sensors allows real-time interpretation with the help of using artificial intelligence technologies.

Digital Agriculture Technologies

Agricultural Robotics

Agriculture is quickly becoming an exciting high-tech industry, drawing new professionals, new companies and new investors. The technology is developing rapidly, not only advancing the production capabilities of farmers but also advancing robotics and automation technology. Agricultural robots are increasing production yields for farmers in various ways. From drones to autonomous tractors to robotic arms, the technology is being deployed in creative and innovative applications (Anonymous, 2017).

Agricultural robots have considerable effects on agriculture. In order to improve the yield and take on repetitive and difficult tasks for farmers, agricultural robots have been developed for harvesting and picking, weed control, autonomous mowing, pruning, seeding, spraying and thinning, phenotyping, sorting and packing applications. Main advantages of using agricultural robots versus the traditional machinery are the accuracy and speed that robots are capable of assisting farmers in the needs of various tasks. Some agriculture robots used for the field applications in precision agriculture are shown in Figure 1.

a **b**

Figure 1. Agricultural robot samples in the field (Anonymous, 2022b; Anonymous, 2022c)

Drone Applications in Agriculture

Drones namely unmanned aerial vehicles (UAVs) are flying robots that can be controlled remotely or autonomously. These unmanned aircraft systems fly with the help of software-controlled flight plans, which are linked with global positioning systems (GPS) and sensors.

Drones that can fly a pre-set course with the help of an autopilot and GPS coordinates are basically consisted of a chassis, propellers, motors, electronic speed controller (ESC), flight controller, radio receiver and battery. While sensors such as accelerometers, gyroscopes, GPS and barometers are used for positional measurements, cameras are frequently mounted for navigation and aerial photography. The 4 propellers of a drone or quadcopter are fixed and vertically orientated. Each propeller has a variable and independent speed which allows a full range of movements (Ahirwar et al., 2019).

Drones equipped with sensors and cameras are now used in the agriculture. Especially in last decade, agriculture drone usage has become an essential part of precision farming applications. Some types of agricultural drones are shown in Figure 2.

Figure 2. Agricultural drones used in the field applications (Anonymous, 2021; Anonymous, 2022d)

Major drone applications and technologies for agriculture summarize as shown below (Ahirwar et al., 2019; Dutta and Goswami, 2020):

- Crop health monitoring
- Water stress monitoring
- Nutrient status and deficiency monitoring
- Diseases monitoring
- Weed Control

- Evapotranspiration (ET) estimation
- Spraying
- Soil and field analysis
- Irrigation

Digital Image Processing Applications in Agriculture

An image is most often represented as a two-dimensional, rectangular grid of pixels. Each position in the image is located using positive integer values on a Cartesian coordinate system. The main distinguishing feature between images and regular Cartesian coordinates is that the origin of the image, pixel (0, 0), is found in the upper left corner of the image. At each coordinate, a pixel represents the color at that point. An example image can be seen in Figure 3 (Gupta and Ibaraki, 2015).

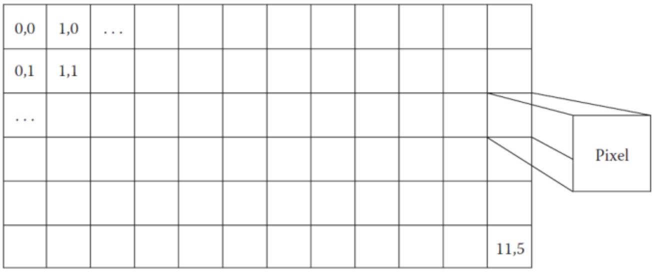

Figure 3. An example image of width 12 pixels and height 6 pixels (Gupta and Ibaraki, 2015)

Image analysis, which is a useful tool for obtaining quantitative information for target objects, is the process of working from raw pixel data to obtaining some useful information from the image, typically a measurement of the objects within (Gupta and Ibaraki, 2015). Digital image processing techniques have been applied to the images acquired from the sensors and they stored on computer for further processing.

Digital image analysis has been widely used as an effective tool for non-destructive analysis of agricultural objects in various fields and applications of an agriculture sector. Not only visible images but also invisible images to human such as ultraviolet (UV), Near Infrared (NIR) and Infrared (IR) are used in the applications of image processing techniques to agriculture (Pandurng and Lomte, 2015). Image processing applications related to the monitoring crop growth; diagnosis of diseases, insect pests and weeds; monitoring nutritional status; monitoring maturity and crop color identification are used in the agricultural field (Xu, 2021).

Some image processing applications about the binary image segmentation, color image segmentation, image filtering and object detection are given in Figure 4, Figure 5, Figure 6 and Figure 7, respectively.

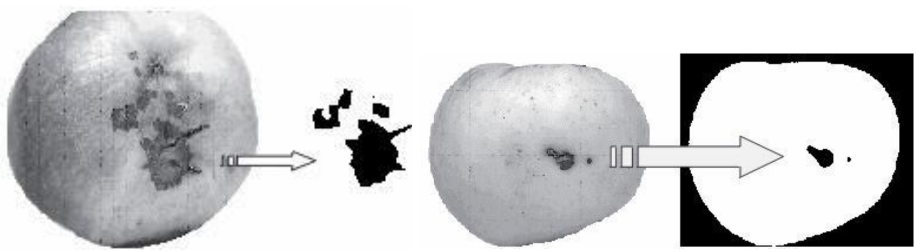

Figure 4. Examples of processed image on apples (Saxena and Armstrong, 2014)

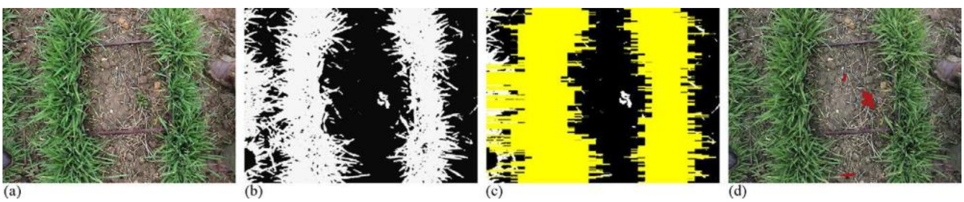

Figure 5. Image processing: (a) input image, (b) segmented image, (c) image after crop row elimination, and (d) final image after the filtering step and weed identification (Saxena and Armstrong, 2014)

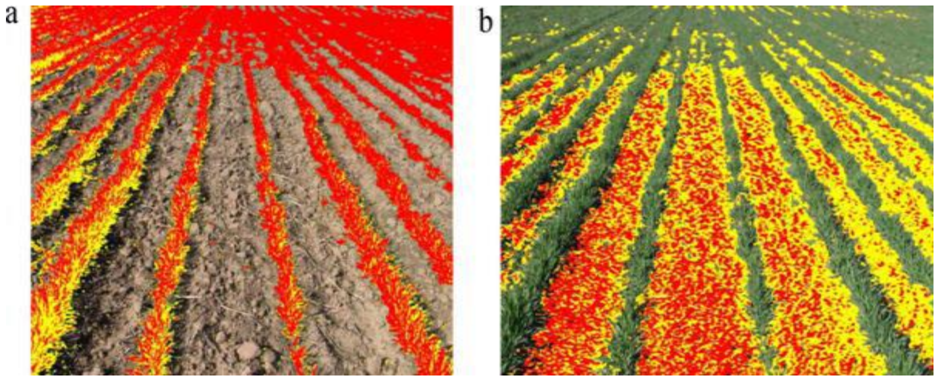

Figure 6. Classification results: (a) two different classes of green plants; (b) two different classes in the soil (Saxena and Armstrong, 2014)

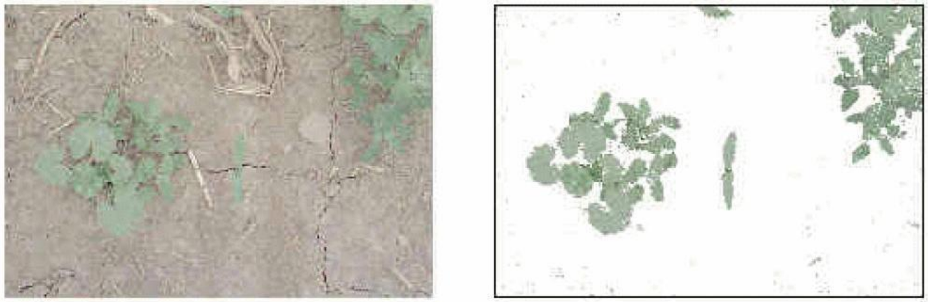

Figure 7. Processing of the color images of the agricultural fields affected by weeds (Saxena and Armstrong, 2014)

Artificial Intelligence Applications in Agriculture

Artificial intelligence (AI) applications has been recently used in agriculture to boost the yield. The main concept of AI in agriculture is its flexibility, high performance, accuracy, and cost-effectiveness (Eli-Chukwu, 2019). Numerous challenges such as improper soil treatment, disease and pest infestation, big data requirements, inadequate drainage and irrigation, etc. have been faced in the agriculture sector. These leads to severe crop loss along with environmental hazards due to excessive use of chemicals (Bannerjee et al., 2018).

Machine learning and deep learning applications have been developed for more automated and more accurate systems for solving agriculture related problems. Traditional agriculture applications have been evolved into the precision agriculture applications with the new technologies.

Today, artificial intelligence is transforming to the agriculture industry as shown in Figure 8 (Anonymous, 2019).

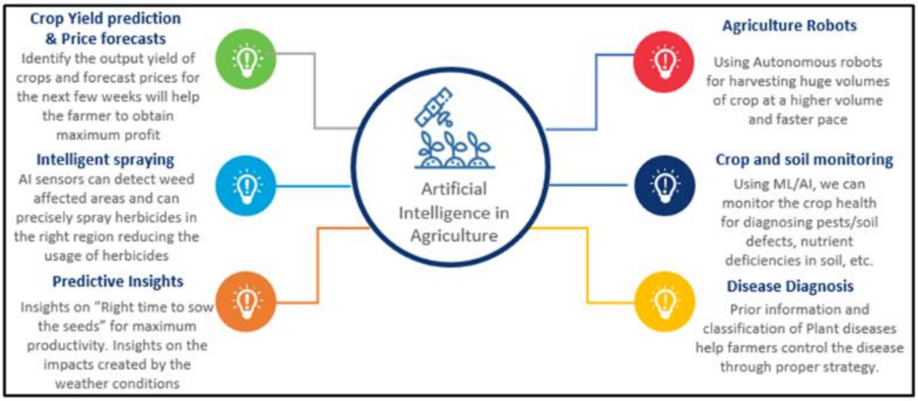

Figure 8. Artificial intelligence in agriculture (Anonymous, 2019)

Machine Learning Applications in Agriculture

Machine learning applications in agricultural production systems has emerged with big data technologies and high-performance computing. Machine learning applications are used in agriculture for (Liakos et al., 2018):

a. Crop management, including applications on yield prediction, disease detection, weed detection crop quality and species recognition
b. Livestock management, including applications on animal welfare and livestock production
c. Water management
d. Soil management

Machine learning gives the machine ability to learn without being explicitly programmed. Machine learning together with IoT (Internet of

Things) enabled farm machinery are key components of the next agriculture revolution (Sharma et al., 2021).

Typically, machine learning methodologies involves a learning process with the objective to learn from "experience" (training data) to perform a task. Data in machine learning consists of a set of examples. Various statistical and mathematical models are used in order to calculate the performance of machine learning models and algorithms. The trained model can be used to classify, predict, or cluster new examples (testing data) using the experience obtained during the training process after the end of the learning process. A typical machine learning approach is shown in Figure 9 (Liakos et al., 2018).

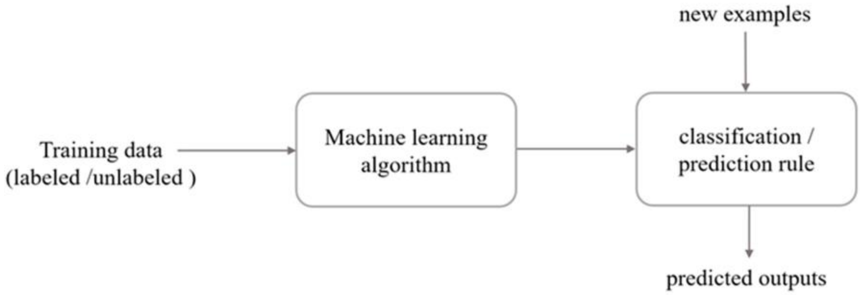

Figure 9. A typical machine learning approach (Liakos et al., 2018)

Machine learning algorithms are frequently classified as either supervised or unsupervised (Jagtap et al., 2022). The learning models in machine learning are given as below (Liakos et al., 2018; Jagtap et al., 2022):

- Regression
- Clustering
- Bayesian Models
- Instance Based Models
- Decision Trees
- Artificial Neural Networks

- Support Vector Machines
- Ensemble Learning

Deep Learning Applications in Agriculture

Deep learning is a data analysis and image-processing method, which has recently gained a lot of attention as a tool, which has great potential and promising results (Magomadov, 2019). In recent years, deep learning algorithms have been widely studied and applied in the agricultural sector.

While CNN (Convolutional Neural Networks), RNN (Recurrent Neural Networks) and GAN (Generative Adversarial Networks) are the most commonly used deep learning algorithms, there are many other sub-category deep learning algorithms such as VGGNet, ConvNets, LSTM and DCGAN (Zhu et al., 2018). Generally, plant and crop classifications are the most common categories of deep learning applications, which are of great use in terms of yield prediction, pest control, disaster monitoring, robotic harvesting and so on (Magomadov, 2019). While traditional methods of feature extraction need the significant human labour, deep learning not only can improve performance in classification and detection, but also can reduce efforts in feature research (Ren et al., 2020).

An example visualization of leaf images after each processing step of the CaffeNet CNN, at a problem of identifying plant diseases, is depicted in Figure 10. As shown, the particular elements of the image that reveal the indication of a disease become more evident after each processing step, especially at the final step (Pool5) (Kamilaris and Prenafeta-Boldú, 2018).

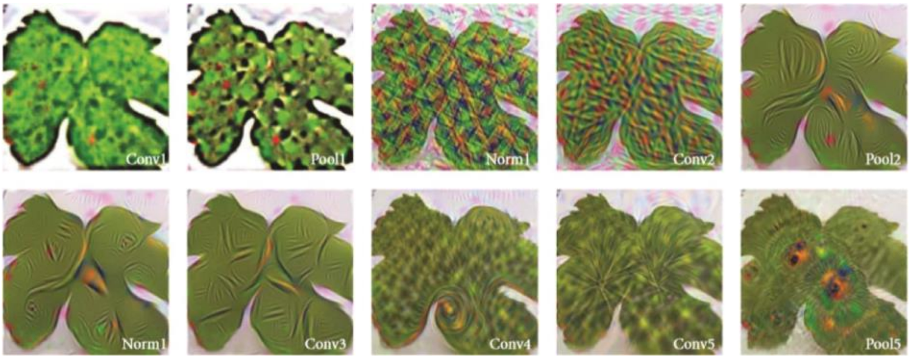

Figure 10. Visualization of the output layers' images after each processing step of the CaffeNet CNN (i.e. convolution, pooling, normalization) at a plant disease identification problem based on leaf images (Kamilaris and Prenafeta-Boldú, 2018)

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CHAPTER 7

SENSORS IN AGRICULTURE

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INTRODUCTION

By 2050, is expected that world population will reach 9.8 billion according to the United Nations report. Consequently, as the global demand for food and agricultural crops elevates, novel and sustainable approaches are needed that employ agricultural technologies focusing not only on agricultural activities for crop production but also on the global impacts concerning the appropriate nitrogen fertilizer use, reduced GHG emissions and water footprints (Pantazi et al., 2020). In addition, minimizing negative environmental impact is important in agriculture (İtmeç et al., 2022).

Precision agriculture and smart farming are emerging areas where sensor-based technologies play an important role. Farmers, researchers, and technical manufacturers are joining their efforts to find efficient solutions, improvements in production, and reductions in costs (Moshou, 2019). Precision farming applications, which are a result of the evolution in agricultural technologies, refer to technologies that enable producers to maximize productivity by using resources such as water, fertilizer and seeds at a minimum. The most important part of these autonomous farming systems is definitely the sensors. Today, systems such as soil analysis, plant growth regulators, weather or real-time water and fertilizer sensors are among the most important management tools of a modern production facility. Farmers can optimize production conditions by measuring the irrigation potential of the plant, yield quality, developmental stages, nutrient levels, pest and disease infections, and various morphology factors such as biomass, leaf area and distribution through sensor technologies.

A number of sensor technologies have been developed for several agricultural conditions including crop yield, soil properties and nutrients, crop nutrients, crop canopy volume and biomass, water content, and pest conditions (disease, weeds and insects), consequently concerning crop status and management. Sensors for soil analysis and characteristics, yield sensing, crops and fruits assessment, weed management and disease detection and classification are sensor technologies used in the agriculture (Pantazi et al., 2020). Digital agriculture uses sensors to measure variables associated with crop growth and production. Thus, these devices can be present in machines that apply inputs, in systems used to monitor plant growth, and in harvesters (Queiroz et al., 2020).

A sensor is a device that detects and responds to inputs from the physical environment. Inputs can include any observable element such as temperature, moisture or pressure. The output is generally data that can be translated or processed into information that supports decision-making. Sensors can be mounted on a variety of platforms including vehicles, unmanned aerial vehicles (UAVs) or drones, aircraft and satellites, as well as being placed in soil, water and on plants or animals. Sensors provide accurate and real-time monitoring of environmental factors that can assist farmers in making better ecisions to increase productivity and lower input costs (Anonymous, 2016).

There are various types of agricultural sensors used in precision agriculture technologies. These sensing technologies provide data in order to help farmers to monitor and optimize crops, as well as adapt to changing environmental factors (Padhiary and Mishra, 2020).

Agricultural Sensor Types

Agricultural sensors collect the information data from the field with a high accuracy and these measurements are used by farmers in order to make farming decisions. Sensors are generally used in monitoring processes such as soil, pest, irrigation, weather and yield. They are also used for spraying applications and precision planting. All these agricultural sensor systems are basically divided into seven in terms of the measurement principles they used. Types of agricultural sensors are:

- Mechanical Sensors

- Electrochemical Sensors
- Optical Sensors
- Location Sensors
- Airflow Sensors
- Dielectric Soil Moisture Sensors
- Agricultural Weather Stations

Mechanical Sensors

Mechanical sensors are used for measuring the soil compaction and identifying the mechanical resistance of the soil. Soil penetration resistance is measured by using a probe that penetrates the soil and records resistive forces with the help of load cells or strain gauges (Padhiary and Mishra, 2020). Tensiometers, which provides precise and reliable force sensing performance, feature sensing technologies that utilize specialized piezo resistive micro-machined silicon sensing elements. Mechanical sensors operate on the principle that the resistance of silicon-implanted piezo resistors will increase when the resistors flex under any applied force. The proportion change between the resistance and the force being applied results in a corresponding millivolt (mV) or milliamper (mA) output level change. The Wheatstone bridge circuit design provides inherently stable mV outputs.

A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. The primary benefit of the circuit is its ability to provide extremely accurate measurements. Its operation is similar to the original potentiometer. The Wheatstone bridge was invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. Wheatstone bridge circuit diagram is shown in Figure 1. The unknown resistance R_x is to be measured; resistances R_1, R_2 and R_3 are known, where R_2 is adjustable (Anonymous, 2022a).

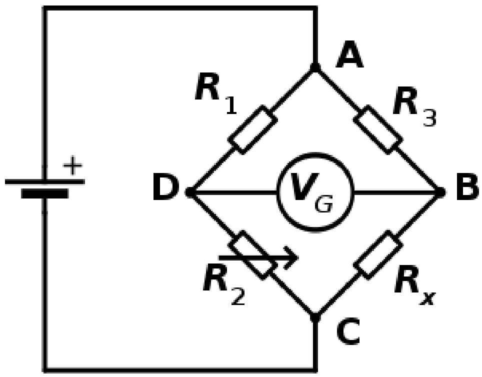

Figure 1. Wheatstone bridge circuit diagram

A mechanical sensor example used in the field is shown in Figure 2 (Anonymous, 2022b).

Figure 2. Mechanical soil sensors for agriculture (Anonymous, 2022b)

Electrochemical Sensors

The chemical properties of soil like pH and other nutrients are identified by using electrochemical sensors. The electrodes of these sensors detect the ions present in the soil. They provide key information required in precision agriculture about the configuration of soil (Padhiary and Mishra, 2020; Parashar and Parashar, 2020).

Plant growth is influenced by complex and mutual relationships, including adequate nutrition, various environmental conditions, photosynthesis, respiration, pests and diseases (Schans and Arntzen, 1991). Monitoring the factors affecting plant growth in real time by using plant sensors based on electrochemical systems is essential to ensure sufficient agricultural production. Electrochemical sensors have the potential to systematically monitor plant health and provide early diagnoses of disease and stress. Thus, these can replace conventional approaches (such as image-sensing technology) for monitoring plant health (Kim and Lee, 2022). As shown in Figure 3, a sensor device is implanted in a tomato plant stem for monitoring variations in the solute content of the plant sap (Coppedè et al., 2017).

Figure 3. A bioristor integrated in a tomato plant (Coppedè et al., 2017)

Optical Sensors

Optical sensors use light to measure soil properties. These sensors measure different frequencies of light reflectance in near-infrared, mid-infrared and polarized light spectrums in order to calculate the soil and properties such as soil texture, organic matter, the moisture content in the soil. Plant colour data is important at analysing the health of a plant based on its leaf by using optical sensors (Padhiary and Mishra, 2020; Parashar and Parashar, 2020). Different plant properties can be measured by using different colour light waves. Two or more of red, green, blue or near infrared (NIR) colour light waves are used by commercially crop sensors (Anonymous, 2022c).

Electromagnetic energy travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays. The human eye can only detect only a small portion of this spectrum called visible light (Anonymous, 2022d). The wavelengths, which are measured in micrometers (µm) or nanometers (nm), used in most agricultural optical sensing applications cover only a small region of the electromagnetic spectrum. As shown in Figure 4, the visible region of the electromagnetic spectrum is started from about 400 nm and finished to about 700 nm. The green color associated with plant vigor has a wavelength that centers near 500 nm (Anonymous, 2022c).

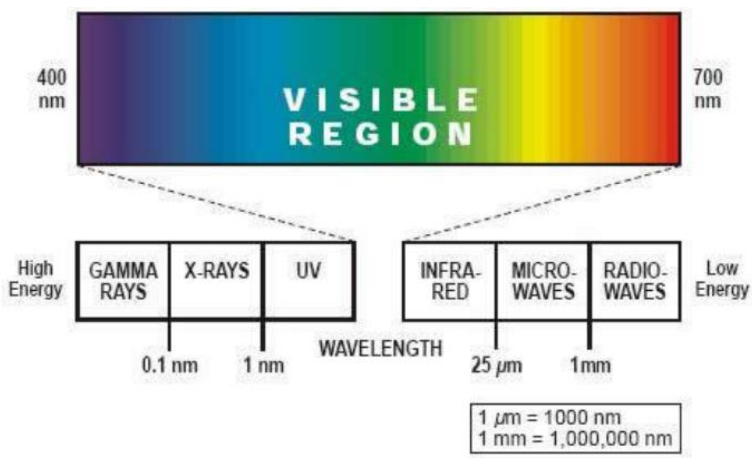

Figure 4. The Electromagnetic Spectrum (Anonymous, 2022c)

There are many applications about the agricultural optical sensing used both the visible and infrared regions. Relative measurement of chlorophyll in the leaves can be possible by sensing the reflectance of green light wavelengths from plants. Crop nitrogen status, the degree of iron deficiency chlorosis, sulfur deficiency, or any other condition causing reduction in green color can be evaluated by using green reflectance. Vegetative indices are developed for visible and NIR light to compare the relative health of crops (Anonymous, 2022c). Some type of optical sensors applied in agricultural crops are shown in Figure 5 (Povh and Anjos, 2014).

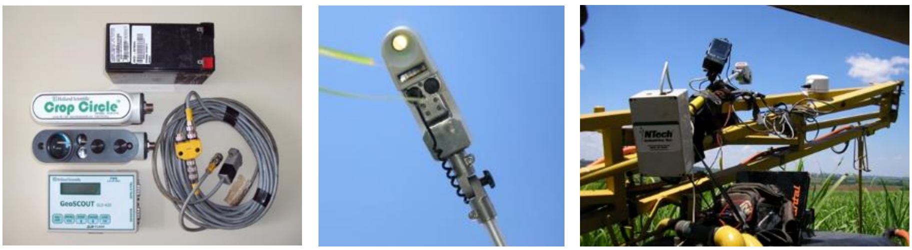

Figure 5. Some type of optical sensors applied in agricultural crops (Povh and Anjos, 2014)

Location Sensors

The longitude, latitude and altitude data in the field are determined by using location sensors according to the signals taken from the GPS satellites. These sensors use minimum 3 satellites to calculate the location with a high accuracy. As known, precise positioning is the cornerstone of precision agriculture (Padhiary and Mishra, 2020; Parashar and Parashar, 2020). Especially in the last years, GPS technology is adopted in vehicle guidance systems for harvesting and farming processes. While the use of auto-guidance systems reduces process overlap and time required to complete the work plan in the field, it optimizes field routing in the farming applications. GPS sensors mounted on a robotic platform is shown in Figure 6 (Chebrolu et al., 2017).

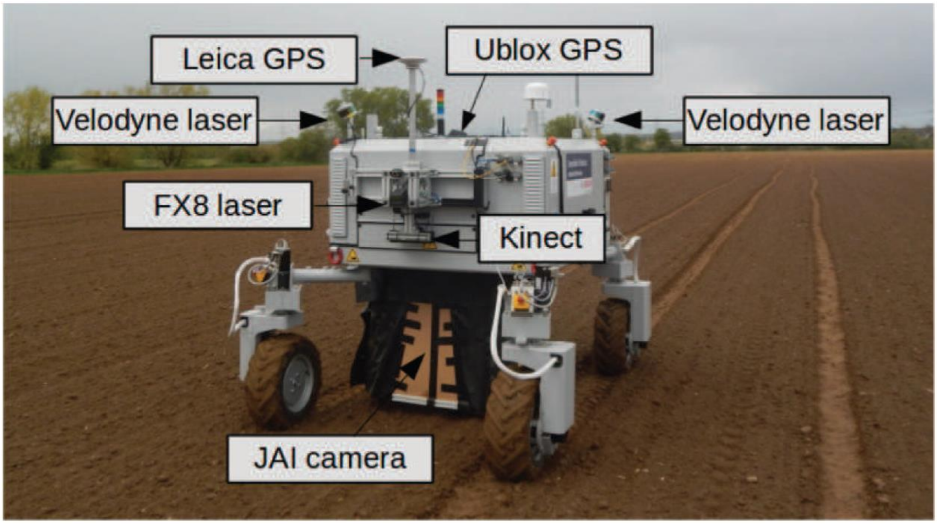

Figure 6. GPS sensors mounted on a robotic platform (Chebrolu et al., 2017)

Airflow Sensors

Airflow sensors are used for measuring soil air permeability by pushing prescribed amount of air into the soil at defined depth. Various types of soil parameters like moisture level, soil type, compaction, the structure of soil etc. are identified and measurements can be made at singular locations or dynamically while in motion (Padhiary and Mishra, 2020; Parashar and Parashar, 2020).

Airflow sensors are also used to record the number of gaseous substances present in the soil at a particular landscape after irrigation or to get an overview of the land that is to be cultivated before the seeding process (Anonymous, 2022e). An airflow sensor is shown in Figure 7 (Anonymous, 2022b).

Figure 7. Airflow sensor used in the farm (Anonymous, 2022b)

Dielectric Soil Moisture Sensors

Dielectric soil moisture sensors are used to measure the change on-resistance of soil due to change in moisture content in the soil by measuring the dielectric constant in the soil. The friction angle of soil and the physical characteristics of soil can be also identified by using dielectric soil moisture sensors (Padhiary and Mishra, 2020; Parashar and Parashar, 2020). The soil dielectric moisture sensors commonly measure the moisture amount by means of a frequency domain (FD) or a time domain reflectometry (TDR) technique (Kuyper and Balendonck, 2001). As shown in Figure 8, there are numerous types of dielectric soil moisture sensors available, each having variable performances (Chandel and Jangilwad, 2020).

Figure 8. Different types of dielectric soil moisture sensors (Chandel and Jangilwad, 2020)

Agricultural Weather Stations

Agricultural weather stations are self-contained units placed across the field to sense various parameters in the field by using a combination of sensors for the local crops and climate. Information such as air temperature, soil temperature at a various depth, rainfall, leaf wetness, chlorophyll, wind speed, dew point temperature, wind direction, relative humidity, solar radiation, location and atmospheric pressure are measured and recorded by using these weather stations at predetermined intervals. Measured and recorded sensor data is wirelessly transferred to a central data logger at programmed intervals (Padhiary and Mishra, 2020; Parashar and Parashar, 2020). Solar panel powered agricultural weather station systems generally include the control module (data logger), embedded cell phone, wind sensor, temperature-pressure-humidity sensor, solar sensor, and adds a rain gauge and soil/surface temperature probe. Such a weather system is shown in Figure 9 (Anonymous, 2022f).

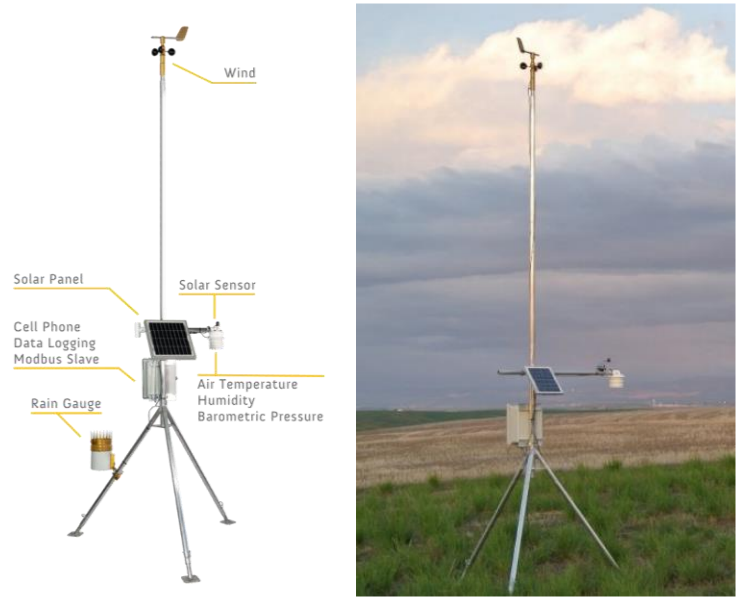

Figure 9. Agricultural Weather Station (Anonymous, 2022f)

Sensor Types in Precision Agriculture

Types of sensors used in precision agriculture systems are grouped in Table 1.

Table 1. Types of sensors for precision agriculture

Group	Sensors
Soil	*Moisture, temperature, nitrogen, carbon, pH, phosphorus, potassium, etc.*
Plants	*Chlorophyll, plant health, NDVI, plant water demands, sugar content, etc.*
Atmospheric	*Temperature, humidity, wind speed, wind direction, pressure, rainfall, etc.*
Water	*Temperature, pH, turbidity, water depth, dissolved O_2, conductivity, etc.*

Advantages of Agricultural Sensors for Farmers

For more than a decade, agricultural sensors used in precision agriculture carry the farmers from traditional farming techniques toward innovative agronomic management practices. Farmers can monitor lively and save data gathered from the field by using Internet of Things (IoT) based stations equipped with advanced agricultural sensors. These sensors can also help to the farmers in reducing the expenses and labour force while protecting the environment. Better decisions about irrigation, fertilization and crop management could be taken by farmers with using of these agricultural sensors.

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CHAPTER 8

AXIAL FAN SELECTION FOR AIR ASSISTED ORCHARD SPRAYERS

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INTRODUCTION

Plant protection products (PPP) are frequently used in agricultural production to improve product quality, safeguard it from negative effects, avoid burning from frost or severe drought, and prevent ripening before the intended time. The usage of pesticides, which are at the forefront of these items and utilized to combat hazardous species, is crucial. In Turkey, total pesticide consumption in 2018 grew by 10.9% from the previous year to 60,020 tons (Anonymous, 2018). The amount of agricultural pesticides utilized is rising despite the annual decline in the areas where agriculture is produced (Anonymous, 2020). An important factor affecting this situation is due to the fact that the application of pesticides cannot be carried out correctly. This is because the droplet particles may evaporate, become airborne, be aimed at an unintended target, or deviate from the intended area. During the application of the pesticide, the phenomenon of move away of the pesticide out of the target is called drift. The uneven distribution of the pesticide on the plant and the high rate of drift cause the pest not to be adequately controlled. In the same orchard, there may be dense pesticide particles in one area within the fruit trees, while insufficient spraying can occur on the other side.

Because of that reason, the desired result cannot be achieved in the pesticide application against the pest, and the plant parts can dry out in the region where the pesticide is accumulated too much. In these cases, the spraying process is repeated, labor and fuel costs rise, and the desired quality of the agricultural product is not obtained. Because qualified operators are expected to use these machines, it is also critical that the machine be designed to avoid and minimize operator error. As a result, it is critical that agricultural spraying machines be partially or completely autonomously controlled.

It is known that the drift may be more, especially in studies conducted in orchard applications. The reason for this is that in applications made with a field sprayer, since the agricultural product remains under the spraying booms, the exposure time of the pesticide to the wind is shorter, and if it is not exposed to the effect of the wind, it reaches the canopy of the plant under the influence of gravity. However, in orchard applications, the droplets must be given extra kinetic energy in order for the pesticide applied while the tractor is moving between the rows to reach the tree canopy, which is possible with air flow. If the operator is unconscious, especially if the droplet carrier air flow is not properly controlled, the pesticide concentration can become excessive (Bayat et. al., 2006).

The pesticide application in orchards, the selection of pesticides is important, as well as the correct application of the pesticide increases the effectiveness of the pesticide. When we look at the basic principles of a successful spraying, the right pesticide, machine selection and qualified operator come to the fore. This machine is expected to send enough air to penetrate the entire canopy of the tree. In horticulture, the distance between the rows of the trees, the length of the rows, the geometric properties of the tree canopy, the vegetative period of the tree and the leaf-branch development (leaf density) directly affect the spraying efficiency (Garcera et al. 2017). No matter how good the chosen machine is, a lack of operator training can result in poor spraying efficiency. Due to this circumstance, researchers and designers of orchard sprayers have created tools that are capable of autonomous spraying and have their own decision-making processes.

It is expected sprayer operators to spray in line with the established standards for compliance with good agricultural practices and certified product production standards in all EU member states nowadays. Exports are frequently hampered by the pesticide's tendency to build up on agricultural products and leave behind a residue. Although 0.7 kg/ha of pesticide is applied per unit area, it has been reported that we are the second country with the highest pesticide residues when the number of unsuitable parties among the 10 countries that export food and feed to EU countries and their consumption per unit area in these countries are examined (Tiryaki et al. 2010). Examining the results reveals that Turkish farmers are unable to apply pesticides efficiently, which could have long-term negative effects on the economy of the nation. When too many pesticides are released into the ecosystem, harm results. This technique can be repeated if the spraying is insufficient.

The air assisted orchard sprayer is one of the machines used in orchard spraying in the world. The reason why these machines are preferred mostly, is their homogeneous distribution of the pesticide and their high air capacity. In air assisted orchard sprayer, a pump is operated with the drive taken from the PTO, and the pump sends the pesticide taken from the tank to the spray nozzles with the desired pressure. However, since the exit speed of the pesticide particles from the nozzles is not at a sufficient level, an additional driving force is needed in order for the droplets to reach the leaves on the tree. For this reason, thanks to the air flow provided by an axial fan driven by the PTO, the droplets coming out of the nozzles can be carried to the tree (İtmec and Bayat, 2021).

When there is insufficient coverage on the leaf surface in orchard spraying, two precautions can be made. These are to improve the dose regulating system (pesticide control with PWM) or to improve the airflow (Miranda-Fuentes et al., 2017). It is known that if the air flow is better adapted to the tree canopy, the problem will be greatly reduced. In this case, the flow rate and air jet of the fan of the orchard sprayer with auxiliary air flow required for the orchard to be sprayed are important. It is possible to simply determine the fan capacity for the possible to be sprayed.

Determination of Fan Capacity

The geometric dimensions of the tree canopy are included in the calculation in working with orchard sprayers with auxiliary air flow was illustrated in Figure 1. It states that the required fan capacity can be determined by estimating the required air volume with the formula given in Equation 1, taking into account these dimensions (Matthews et al., 2014);

$$Q_T = H.W.L \quad (1)$$

Here;

Q_T: The amount of air volume that needs to be displaced in the garden for a good spraying (m^3)

H: Canopy height (m)

W: Tree canopy width at half the canopy height (m)

L: Row length (m)

If the row length is divided by the tractor travel speed (V_T), the total time collapsed (t) for spraying is found as;

$$L/V_T = t \quad (2)$$

The required air flow is calculated by dividing the amount of air that needs to be replaced in the garden by the total time taken for spraying.

$$\frac{Q_T}{t} = V \quad (3)$$

However, the leaf area index was not taken into account in this calculation. The canopy geometries of the trees in the same orchards and planted in the same time period may vary. With the method described above, the fan capacity of the auxiliary air flow orchard sprayer can be roughly determined, but for a good coverage, the airflow should be adjusted proportionally for each tree as the geometry of each tree will vary (Bayat et al., 2020).

Figure 1. Necessary parameters for calculating air volume

Real Time Tree Canopy Geometry Measurement

Measuring the tree canopy and spraying in accordance with the tree canopy geometry are among the most popular topics in the field of spraying in recent years. Tree canopy sensing systems can be realized by scanning with laser or ultrasonic sensors.

Schumann and Zaman (2005), measured the tree canopy from 10 different heights and divided the tree into horizontal slices at 10 different heights. By deducting the distance from the tree centre at each measured height, they were able to compute each region's area by treating the area of each slice as circular (Figure 2). They discovered the tree canopy by inductively adding the volume calculated in all 10 regions after multiplying each ultrasonic sensor area by the scanning height. Following are the locations of each area computed on the tree canopy:

$$A_c = 2\sum_{i=1}^{i=10}(0.5\,D_r - D_{Di})D_s \qquad (1)$$

Here, A_c denotes the computed area for each slice, D_s denotes the separation between ultrasonic sensors, D_{Di} is the separation between any two ultrasonic sensor locations, and D_r denotes the distance between rows. Using this formula as a starting point, the volume of a tree is;

$$V_{TC} = \sum_{i=1}^{i=n} tS_i A_{Ci} \tag{2}$$

In this formula, A_{Ci} is a calculated tree section, n is the number of scans completed, S_i is the feed rate, and t is the total time taken to complete a scan.

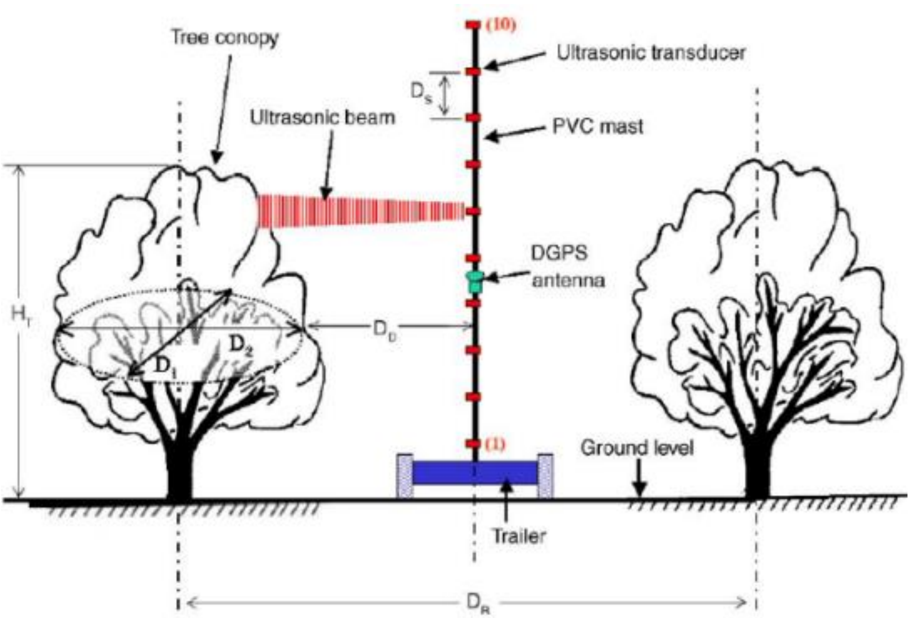


Figure 2. The terminology used by Schumann and Zaman (2005) when determining their mathematical equations

Determining The Air Capacity/Velocity to be Delivered to The Tree

Practical determination of sufficient air speed

The practical strategy shown in Figure 3 is employed for low drift and good coverage on the target surfaces depending on the tree vegetative growth

(Deveau, 2015). For the use of this practical method, plastic strips that are 25 cm long and can typically fly in a light construction are fastened to the ends of the branches on the outer part of the tree canopy in the direction of the airflow. If the connected plastic strips fly within 25°-45° angles from the vertical plane, it is commented that the air velocity is appropriate. However, Tsatsarelis (1979) determined the maximum air velocity at the exit of flat-leaved trees as 3 m/s in his study. Balsari et al. (2008) stated in their study that for a good leaf surface coverage, the air velocity should be 5 m/s at the exit of the tree canopy. Therefore, although the tree species changes, the air velocity is expected to be between 3 and 5 m/s after the tree canopy (Bayat et al. 2020).

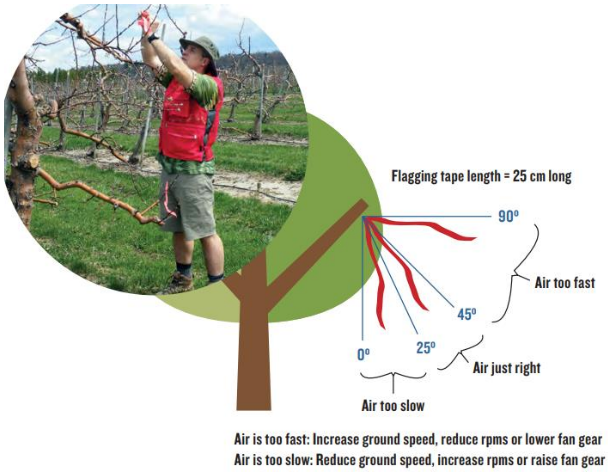


Figure 3. Adjustment of air velocity according to tree vegetative growth (Deveau, 2015)

Theoretical Determination of Sufficient Air Velocity

Mathematical Model to be Used in the Free Atmosphere Zone from the Sprayer Air Jet Outlet to the Tree Canopy

There are many studies on the mathematical model of the distribution of the air jet of the fan of the Auxiliary Airflow Orchard Sprayer in the free atmosphere. Frisio et al. (2015) modernized the jet theory with their work (Figure 4).

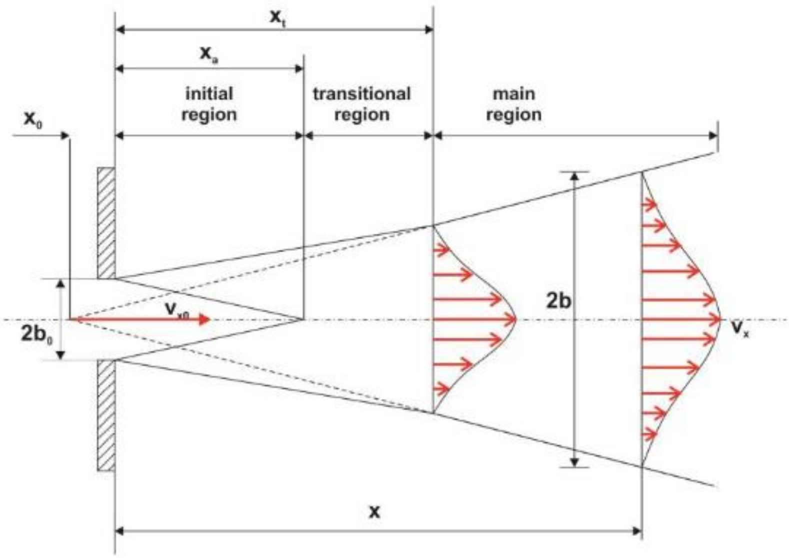


Figure 4. The sections of the air jet and the visualization of the mathematical model on the free body diagram (Frisio et al., 2015).

The average velocity of the air jet of the fan before it enters the tree canopy and its magnitude at any distance after it has fully developed (development zone) can be calculated with the following formula (Fox et al., 1982). At any distance x, how much the air coming out of the jet will decrease is calculated by Equation 4.

$$\frac{u}{u_m} = \left(\frac{b_o n_2 (r_o - x_{o_n})}{A_2 c_m (x + r_o)(x - x_{o)}} \right)^{1/2} \tag{4}$$

From the formula, there is the ratio of the jet velocity (u) to the velocity at any point (u_m). A_2 Integral parameters (0.316) of main region velocity profile. Half-length of jet velocity b_o, integral parameter n_2 (0.76), radius of r_o air jet exit, x_o radial distance from jet center, x polar position to fan center and x_{on} distance from outlet to apparent origin of jet boundary layer

The Mathematical Model to be Used in the Canopy of the Tree for the Air Jet

The air jet of the axial fan of the orchard sprayer passes across the tree canopy by decreasing its kinetic energy with the effect of these resistances, taking into account that leaves and branches impose a resistance effect along the air flow. The propagation of the air jet in the tree was mathematically modelled by Frisio et al. (2015) (Figure 5). However, the study considered the ratio of leaf-branches per unit volume as homogeneous.

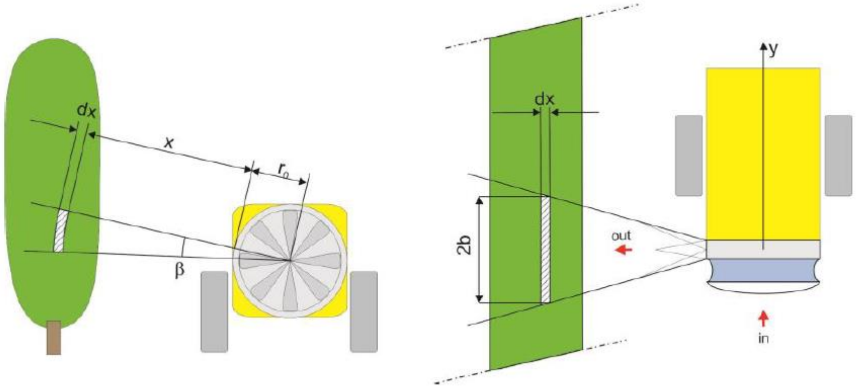


Figure 5. Mathematical model of the progression of air in the tree (Frisio et al., 2015).

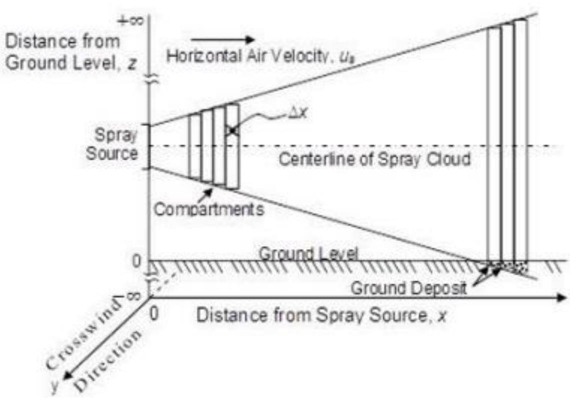
Accordingly, Frisio et al. (2015) expressed the air jet in the tree as the following mathematical model in their study:

$$v_x = v_{xe}\frac{G(x_e)}{G(x)} - \frac{\mathrm{k}\rho_l}{16}\left[(2x - x_o + r_o) - (2x - x_o + r_o)\frac{G(x_e)}{G(x)}\right] \quad (6)$$

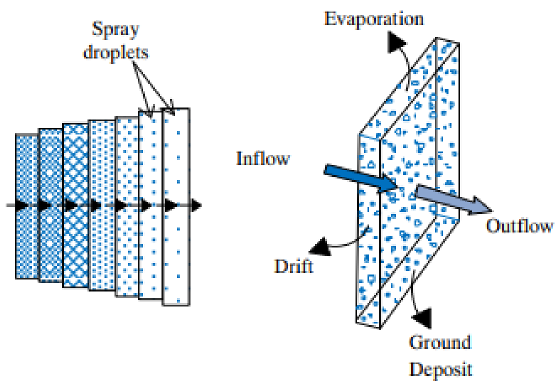
Depending on these data, $G(x_e)$ is the geometric properties of the air at the outlet side and G(x) is the geometric properties of the air at any point; r_o is the distance from the fan hub, xo is the distance from where the canopy begins, x_e is the distance from where the canopy of the tree ends. This formula can be used to determine the air velocity at the tree exit based on the leaf density. Leaf density and other variables will be added to the equation and the air output velocity will be solved in this way since the needed air velocity at the tree exit is anticipated to be between 3 m/s and 5 m/s. In order to disclose the formula, the mathematical model was developed under the assumption that the tree's branches and leaves are uniform throughout.

Droplet Losses Due to Fan Velocity

There are different mathematical models, for the air velocity applied from the axial fan of the orchard sprayer enters the tree. The reason is the air resistance in the atmosphere is different from the resistance in the tree canopy. Since the leaves and branches in the tree create resistance, the air jet must be solved with a different mathematical model in this region. In this regard, Larbi and Salyani (2012a) were interested in the geometry of the sprayed liquid (Figure 5a). They demonstrated how the jet propagates in the open atmosphere. In their second study, Larbi and Salyani (2012b) put forward a mathematical model that reveals how this geometry spreads within the tree canopy. As can be seen in Figure 5b, when the sprayed droplets are considered to move from left to right, the kinetic energy of the air in the right rectangle will decrease. The amount of droplets contained in the air will decrease compared to each rectangle on the left. For a good spraying efficiency, the recommended application volume for the pest species should be distributed equally per unit tree volume.



(a)



(b)

Figure 5. (a) The general geometry of the spray (Larbi and Salyani, 2012a) and (b) distribution and the variation of the pesticide+air (mass flux) mixture depending on the branch and leaf at each dx distance (Larbi and Salyani, 2012b).

Accordingly, Larbi and Salyani (2012b) explained the mathematical model of mass transfer showing the losses in the tree. As the spray cloud discharged from an airblast sprayer passes through the target canopy, the spray droplets undergo further size reduction due to evaporation. In addition, part of the spray is captured by the canopy to result in deposition, and part deposits directly on the ground or indirectly through runoff from leaves due to excess deposition.

$$\frac{dm_x(t)}{dt} = f_{in,x}(t) - f_{out,x}(t) - f_{vap,x}(t) - f_{dep,x}(t) - f_{runoff,x}(t) - f_{grnd,x}(t) \quad (5)$$

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CHAPTER 9

CHEMICALS THAT INCREASE THE APPLICABILITY OF PESTICIDES: ADJUVANTS

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INTRODUCTION

Modern agriculture depends heavily on the usage of pesticides, which also improves crop quality and output. It is essential to apply agricultural pesticides effectively and without drift, which is the wind-driven movement of sprayed chemicals into unintended locations (Bayat et al., 1999). In addition to droplet evaporation, drift-prone droplets may land outside of the intended spray pattern of a nozzle in the field or be carried away by the wind to an area beyond the field. Drifting pesticides have the potential to harm sensitive plants, wildlife, people, and water supplies, leading to ineffective pest management (Özlüoymak, 2022).

Due to drift issues, insufficient pesticide application results in yield loss because the target plant is not adequately protected from pests. On the other side, excessive pesticide deposition on the plant target can potentially cause phytotoxicity. The physical and chemical characteristics of the pesticide, the spraying apparatus, the technique of administration, the size of the droplets, and the weather conditions are the main determinants of drift.

The airborne drift phenomenon depends heavily on droplet sizes. The size of the droplet produced by the spray nozzles is influenced by the viscosity and surface tension of the liquid, among other physical characteristics. Spraying fluids with high viscosity and surface tension frequently results in larger droplets. By employing the proper tools and spraying techniques in favourable weather, optimizing variables like sprayed liquid viscosity and surface tension, evaporation level with drift lowering additives, and increasing operator experience, the amount of pesticide on targets can be kept within acceptable ranges.

The majority of plant protection products (PPP) created today aim to prevent pesticide drift and improve pest management. In general, the adjuvant manufacturers claim that as their products' viscosities rise relative to water, their droplet sizes rise as well, decreasing the possibility for drift. In terms of factors like the adhesion of adjuvants with various formulations used in pesticide application after spraying on the target surface, their distributions on these surfaces, and the availability of evenness of distribution, it is also crucial (İtmeç et al., 2022)

Many pesticides require the addition of an adjuvant, and some do not. When applying fungicides, insecticides or herbicides without a recommended adjuvant, 30 percent to 50 percent reduction in pest control can be expected. Adjuvants may cause damage to a plant if the wrong adjuvant is used or if it is used at too high a concentration.

Adjuvant is a broad term describing any additive to a spray tank that enhances pesticide activity. Examples of adjuvants are surfactants, spreader stickers, crop oils, antifoaming materials, buffering agents, and compatibility agents. Surfactants are adjuvants that facilitate and accentuate the emulsifying, dispersing, spreading, wetting, or other surface modifying properties of liquids (Czarnota and Thomas, 2013).

How Do Adjuvants Works?

Adjuvants are substances that are chemically and physiologically active, NOT chemically inert. Some adjuvants have the potential to be mobile and contaminate surface or groundwater sources, and they have noticeable effects on both plants and animals. Use of adjuvants near water should be avoided at all costs because some aquatic species may be adversely affected by them.

Understanding how water functions is helpful in understanding how adjuvants function. A lot like a magnet, each water molecule is bipolar, meaning it carries both a positive and a negative charge. The positive and negative forces pull together when you combine multiple water molecules. A water droplet's surface molecules are kept together with greater force than its core water molecules. Because of surface tension, many items may be unable to dissolve into solutions and become moist. The majority of surfactants have a polar head (hydrophilic head) that prefers water and a non-polar tail that does not (hydrophobic tail).

These parts of the surfactant molecule aid in breaking the surface tension of the water, which makes it easier for the pesticide to disperse uniformly on a surface and reach its intended target. There are a number of possible outcomes when water molecules interact with dissimilar substances. The two forces oppose one another if the substances have a similar charge. The two forces will be drawn to one another if their charges are different. There won't be a response if there are no charges. On the majority of hydrophobic surfaces, water will bead when applied. Surface tension, which is the cause of the beading, can be decreased by the addition of surfactants (Figure 1). More pesticide can reach its target because higher pesticide coverage results from lower surface tension in a pesticide solution.

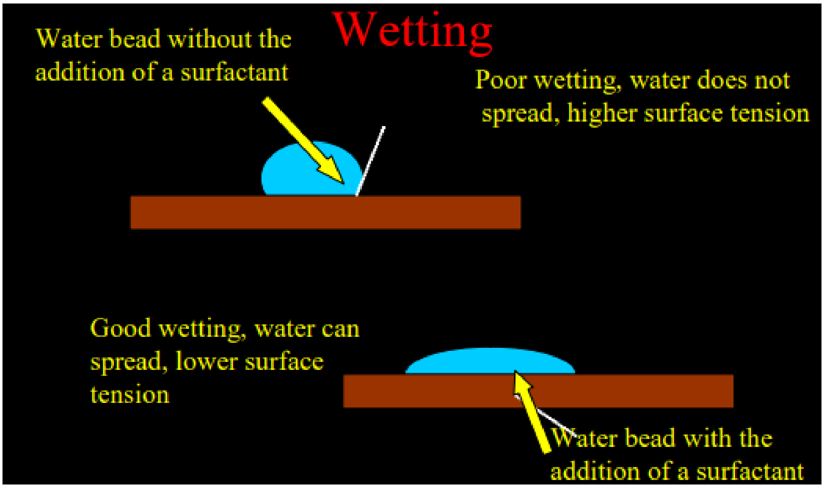

Figure 1. Water beads and how they are affected by surfactants (Czarnota and Thomas, 2013).

Which adjuvant is needed?

Choosing an appropriate and effective adjuvant can be daunting. To begin with, it is sometimes difficult to determine which adjuvants actually meet the recommendations on the herbicide label. There are hundreds of adjuvants available, and choosing the best one(s) will depend on the plant species targeted, its phenological stage, site conditions, current environmental conditions, and the method of application, etc. Contrarily, adjuvant formulations that have little biological or chemical effects are frequently referred to as "inert," which is somewhat similar to the definition of the word "inert" as it is used in the study of chemistry. Another confusing factor is that even if an adjuvant formulation is offered under the same name, adjuvant producers occasionally alter its chemical composition. The fact that some adjuvants or adjuvant mixtures may occasionally be more hazardous to some non-target organisms than the herbicide itself should be taken into account.

Some factors to consider when choosing an adjuvant

- Environment
- Site conditions (Aquatic or terrestrial? In sensitive areas?)
- Current conditions (Air temperature? Windy?)
- Water chemistry (Hard or soft water? Low or high pH?)
- Target(s)
- Species and growth form
- Phenological stage
- Dense or sparse growth? (Will it warrant high volumes of spray?)
- Barriers to penetration (Waxy, hairy or thick leaves?)
- Method of application (foliar spray, boom spray, stump paint, hack & squirt)
- Other

- Product interactions or compatibility issues
- Order of mixing into the tank mix

Tips for adjuvant selection

- Buy high-quality adjuvants
- Be cautious that some adjuvants might be more harmful than the pesticide itself.
- The least harmful adjuvant that fits your demands should be chosen.
- Adjuvant brands are rarely included on pesticide labels; instead, the general kind of adjuvant, such as nonionic surfactant, agricultural
- It is not always necessary or desirable to add an adjuvant
- Use good application techniques and calibrate equipment often.
- Calculate the cost of adjuvant based on % active ingredient (Tu et al., 2001)

Types of adjuvants

A wide range of non-pesticide products has now been marketed as adjuvants (Figure 2). Manufacturers of these products claim that their use will enhance the performance of a pesticide and in some cases reduce the amount of active ingredient that needs to be applied. It has become increasingly recognised that an adjuvant may be required in certain situations. Indeed, some agricultural companies, have marketed specific adjuvants for tank mixing with their pesticide. Although not pesticides, adjuvants do require registration as they affect the performance or pesticides.

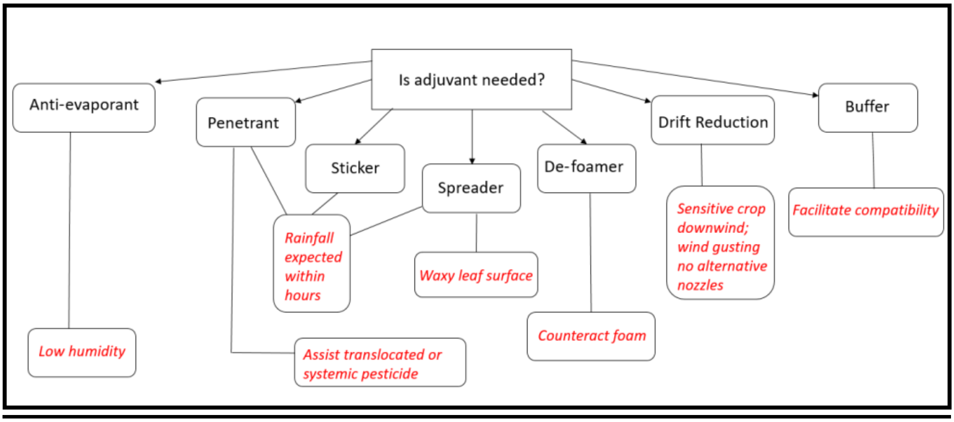

Figure 2. Chart to show different types of adjuvants (Matthews et al., 2014).

Surfactants

The name is derived from **surf**ace **act**ive age**nts** and these compounds facilitate or enhance the emulsifying, dispersing, spreading, sticking or wetting properties of the herbicide tank mix (includes spray modifiers). Additionally, surfactants can directly affect how well a herbicide penetrates the surface of leaves and stems by altering the crystalline structure and viscosity of waxes on those surfaces (Kirkwood, 1999; Toraman, 2019).

Surfactants can be classified in four groups on the basis of the ability to ionize the aqueous solution. Those groups are:

Nonionic — are the most commonly used in agriculture and can be mixed readily with any herbicide. They produce little or no ionization in water (no electrical charge). Organosilicone and silicone surfactants are two types of nonionic surfactants.

Cationic — are not often used with herbicides. They have a positive charge,

Anionic — rarely used with herbicides, but mainly used in cosmetics, household cleaners, many domestic detergents, etc. They have a negative charge, and

Ampholytic (amphoteric) — have a both positive and negative charge, that is, in aqueous solution are capable forming cations or anions (Pacanoski, 2014).

Oil Based Adjuvants

There are three categories of oil based adjuvants: crop oil concentrates, crop oil, and vegetable oil. Oil based adjuvants slow the drying of the herbicide droplet on the leaf surface, which increases the potential for herbicide absorption. Oil based adjuvants also can improve penetration into the leaf by modifying (solubilizing) leaf surface waxes. These oil based adjuvants can cause injury (leaf burn) if applied with a herbicide under less than ideal moisture conditions.

- Crop oil concentrates (COCs) are primarily composed of emulsifiable petroleum-based oil (83 to 85%) and a small percentage of a nonionic surfactant. Typical recommendations are 1–2 quarts per 100 gallons (or 1 to 2.5% v/v). COCs are often known as penetrating agents.
- Vegetable oil concentrates (VOCs) are primarily a crop oil such as cotton, linseed or soybean oil and a small percentage of a non-ionic surfactant. Methylated seed oils (MSOs) are vegetable oils that have been modified through a process of esterification. MSOs are typically recommended at 0.25 to 1.0% v/v of spray solution.
- Crop Oils are not vegetable based. They are more than 95 percent paraffin or naptha-based petroleum oil with 1 to 2 percent nonionic surfactant. Basic crop oils are not commonly used with herbicides (Bell et al., 2019).

Emulsifiers

Emulsifiers work by coating tiny particles or groups of liquid molecules, preventing them from coagulating with other molecules of a similar size. The emulsifiers enable the mixing of oil and water solutions. These products are typically added by the manufacturer and are frequently combined with petroleum-based pesticides to aid in their mixing with water.

Defoaming Agents

To stop or slow down foam generation in the spray tank, defoaming agents are used. In combination with the kind of surfactant used to manufacture the insecticide, foam is produced when air bubbles appear as a result of spray tank agitation.

Deposition Agents

These adjuvants, often known as "stickers," make a pesticide more adherent to a target's surface. The amount of pesticide that is washed off the surface during irrigation or rain is reduced as a result. Additionally, some substances can inhibit a pesticide's destruction from ultraviolet radiation and deposition agents can lower a pesticide's evaporation rate. Many deposition agents also contain wetting agents, resulting in a premixed solution that distributes and adheres to the desired surfaces.

Buffering and Conditioning Agents

Most insecticides, fungicides, and herbicides work best in water that is slightly acidic and has a pH between 4.0 and 6.5, with a preferred range of 5.5 to 6.5. Sulfonylurea herbicides are the exception; they work best in water that has a pH of 7.0 or above. Pesticide solutions are more susceptible to degradation or breakdown when their pH value is higher than 7.0. When the pH of the water is 9.0, a pesticide that is stable in water and has a pH level of 5.0 can, in certain situations, lose half of its potency in as little as 15 minutes. Adjuvants that act as acidifiers reduce the pH of the water in the spray tank, however they may not always keep it there. Buffers tend to stabilize the pH at a relatively constant level.

Anti-condensates

Anti-condensates have a surfactant-like effect that helps water flow evenly across the surface of the film rather than forming droplets on the plastic and dropping onto plants. The water can be conveyed away as a thin sheet along the pipe or plastic film by forming a film. They are quite effective but should never, ever be used on soil or plants.

Drift Control Agents and Thickeners

Droplet size, wind speed, and spray boom height all influence drift. Droplets that are finer (150 microns in diameter or less) have a tendency to stray from their intended application sites. By raising the average size of the droplets, drift retardants or deposition aids enhance the on target placement of pesticide sprays. Coarser spray droplets are created by the binding of water molecules by these adjuvants. As their name suggests, thickeners make spray mixes more viscous (dense). After the pesticide has been sprayed, these adjuvants are employed to prevent drift or slow evaporation of the spray droplets. When employing systemic pesticides, it's crucial to slow evaporation because it lengthens the time the plant has to absorb them.

Penetrants

In order for other chemicals to interact with plant or insect epidermal tissue and access the spaces between the epidermal cells, commonly referred to as "cell free space," penetrants disintegrate or penetrate waxy layers on leaves. Penetrants may contain agricultural oils, complex alcohols, petroleum by products, and other substances derived from hydrocarbons. They perform effectively with very particular crops produced outside and under very particular environmental circumstances.

Natural Surfactants

Coconut oils, palm oils, castor oils, lanolins, wheat amino acids, and other materials have been used in the past, but there has been little research to prove that these products are effective when combined with pesticides (Czarnota and Thomas, 2013).

Colorants

Spray solutions are colored with colorants so that applicators can quickly identify regions that have already been sprayed.

Environmental Effects of Adjuvants

From an environmental aspect, adjuvants can weakly bind herbicides and release them slowly in order to prolong the efficacy of herbicides and to minimize their leaching into groundwater.

Pesticides are never used alone but in combination with adjuvants. Agricultural preparations of pesticides include adjuvants mixed with an active principle to increase toxic effects. For glyphosate-based herbicides, the active principle primarily targets the EPSPS enzyme but needs adjuvants such as polyethoxylated tallow amine to penetrate into plant tissues and cells. These adjuvants can also be toxic in their own right; numerous toxic effects have been reported in humans and the environment. However, adjuvants are regulated differently than active principles, and their long-term toxic effects are generally ignored and thus missing from pesticide risk assessment procedures. (Mesnage and Antoniou, 2018).

CONCLUSION

The interaction between the herbicide, adjuvant, and plant environment can be inferred from all of the prior research that has been mentioned as a complicated system. The best use of adjuvants depends on an understanding of their various functions in the behaviour of herbicides. Adjuvants can enhance the biological activity of the active ingredient in herbicides, the efficiency of spray application, and the economics of herbicide applications, but under certain conditions they can also have unfavourable consequences. As a result, there isn't a single adjuvant that can enhance the effectiveness of all herbicides, all weeds, or all environmental factors. The adjuvant and herbicide used, as well as the proportions utilized, must be customized to the circumstances of each application. Besides, sometimes adjuvants can decrease the killing power of the herbicide.

There is no universal adjuvant that can improve the performance for all herbicides, against all weeds, or under all environmental conditions. The herbicide and adjuvant selected and the relative amounts used must be tailored to the specific conditions of each application.

Viscosity and surface tension are the main parameters that affect droplet generation. Therefore, the nozzle-adjuvant relationship must be investigated by companies for better droplet generation.

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