# Design of a Sprayer for Weed Control in Agriculture Using Ultrasonic Sensor

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***Abstract***

*This study led to the development of an innovative prototype aimed at reducing pesticide use and increasing small farms' access to automation technologies. Developed to increase the competitiveness of small-scale farmers and optimize resource use, this prototype aimed to provide a solution to one of the biggest challenges facing modern agriculture.*

*In this study, weeds growing between sunflower rows are detected by an ultrasonic system. A gasoline-powered backpack atomizer is placed on a 4-wheeled, hand-pulled track designed to move between sunflower rows. The measurement results obtained by using water-sensitive papers between the rows and on the rows in the application area were compared with the classical spraying application carried out by attaching it to the back for control purposes. Success was demonstrated by checking where the spray reached.*

*As a result, the developed prototype fully detected all plants higher than 5 cm. He was able to spray on all plants. However, spray liquid has also been detected in row crops that should not be used. This problem was seen as a problem that could be solved by changing both the spray nozzle type and height. In addition, when looking at pesticide consumption, 73.6% less consumption was achieved. This is an important result both in terms of economy and preventing environmental pollution.*

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***Key words:*** *Sprayer, ultrasonic, sensor, droplet, pesticides, ardiuno*

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## 1.Introduction

Agricultural production is of great importance for our country due to its contributions in various areas such as feeding the national population, supplying clothing needs, contributing to the national income, aiding in the country's development, providing the raw material needs of the industrial sector, creating a healthy environment, transferring capital to industry, contributing to exports, maintaining ecological balance, ensuring sustainability, and many other similar aspects.

The efficiency and profitability of agricultural production depend on the effective and economical control of pests. Overusing chemicals to control weeds can lead to unwanted environmental pollution and potential losses during harvest. Farmers have long been dependent on the use of herbicides to control weeds in their fields. Increasing costs, potential health risks, and environmental threats have led to the search for alternative control methods. Weeds competing with crop plants for light, water, and nutrients can significantly decrease the yield and quality of crops, often reducing them. Manual weeding requires human labor and is costly (Hansson & Ascard, 2002). Automated weed control necessitates the development of a detection and activation system.

Growing healthy and productive crops, similar to most plants, requires contending various factors like climate and soil conditions. For instance, the cost of plant protection for an enterprise producing oilseed sunflower in the range of 70-250 da is approximately 2.3 $/da. This means 89.80% of the necessary expenses for one season are used for plant protection (Düğmeci & Çelik, 2020). In regions where sunflower agriculture is practiced, weeds like dog grape, fathen, knotweed, shepherd's purse, cock's comb, shepherd's rod, wild purslane, and prickly paddy are harmful. One of the methods used for weed control is hoeing. In sunflower cultivation, hoeing, which involves loosening the soil surface to retain moisture, is utilized to achieve high yields and control weeds. However, hoeing is a meticulous and continuous job, leading to time loss and increased workload. Another method used is pesticide and herbicide applications.

When considering only agriculture, the control against insects is primary, but the control of weeds is also a major problem for our farmers. Weeds occupy space, spread disease, and become a hindrance. They cause increased consumption of products in machine operations, spraying, and fertilization. For these reasons, herbicide use is the second most common method.

With the advancement of technology and its integration into agriculture, the use of robotics for weed control has become possible (Sujaritha et al., 2016). The current technique, robots, allows for the mechanical or chemical control of weeds without human intervention. Robotics replace the human labor involved in weed control, making weed management easier for producers.

Today, agricultural control against weeds uses robotic systems that incorporate technology integration, thinking ahead to the future. Scientists have employed unmanned aerial and ground vehicles as a technological move against weeds, which pose a significant problem in agriculture (Pérez-Ortiz et al., 2016; Lottes et al., 2017; Grimstad et al., 2017). In agricultural, robots observe differences such as color, shape, texture between weeds and crop plants, and use computer-based software systems, electronic equipment, and parts that provide mechanical or chemical spraying against weeds (Guijarro et al., 2011).

While pesticide use is widespread, it brings cost and environmental pollution. Pesticide use, when applied carefully and in necessary amounts, yields positive results. This is precisely what we aim to implement in our project: minimal pesticide use, high yield, and successful plant protection.

With this goal, this project will implement a precision spraying system that can be pushed by hand, using ultrasonic sensors to spray pesticides only on detected weeds, thus reducing the amount of pesticide used, product damage, and environmental pollution, and increasing efficiency by reducing costs

## 2. Materials and Methods

Agriculture is a key sector fulfilling a fundamental need for human survival. However, weeds pose a serious threat to plant cultivation, as they can reduce productivity and damage planting areas. Traditional methods of weed control are often time-consuming and labor-intensive.

Weeds, from home gardens to agricultural fields, are undesirable plants that can make plant cultivation difficult and reduce yield. Various methods are available for detecting and controlling these weeds. Ultrasonic sensors can be an effective technological tool for the detection and control of weeds.

Ultrasonic sensors measure distance using sound waves. These sensors analyze reflected sound waves to determine the distance to objects. By detecting the different way sound waves are reflected off weeds compared to other vegetation, they can effectively identify weeds.

### 2.1. Material

This study was conducted in the Agricultural Faculty of Namık Kemal University and in sunflower production areas. The project activities have been described in two parts: prototype manufacturing and field trials. The prototype consists of several components as shown in Figure 1.

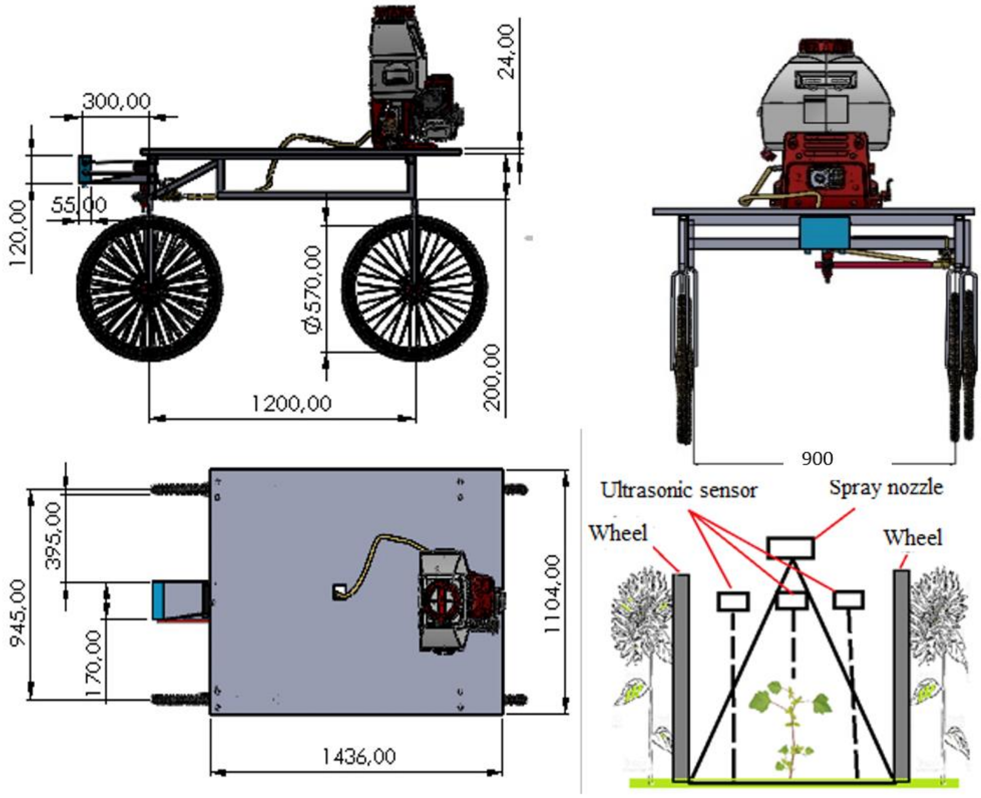


Figure 1. Prototype

## Backpack Sprayer (Motorized)

It comprises a tank, an air tank, a hand-operated pump, a hose for operating the pump, and a spray rod. It is a sprayer weighing 9 kg with a 25.6 cc cylinder volume, 1.4 Hp motor power, 25-liter pesticide mix tank capacity, and 0.9-liter fuel tank capacity (Hyundai Turbo 768 Backpack Type Atomizer). It is mounted on a carrier vehicle. A pressure-resistant hose (Adjustable Hose Attachment Sleeve ½'') is used in the system. Additionally, a oil manometer (0-10 bar) has been installed to monitor the pressure. To supply the electrical needs of the system, 2 Taba-Atex, 12V 7000mAh dry batteries are used.

## Carrier vehicle

It is composed of a chassis and 4 bicycle wheels. The chassis is made of metal profiles, and a carrier surface made of sheet material is placed on top and welded. The wheels (26'x1.95') allow it to be pushed and moved. Technical specifications are shown in Figure 1. Other components (backpack sprayer, control system, sensors, and system of pipes) were then mounted on it. Overall dimensions of the vehicle; Width: 1500 mm, Length: 1720 mm, Height: 950 mm. A box of 300x180 mm base area and 2 mm sheet material has been bent and mounted to carry the control box and batteries at the front of the vehicle (Fig. 2).

**Figure 2. The carrier vehicle**

## Ultrasonic Sensor

Tree ultrasonic sensors are used in the system. A microcontroller is usually used for ultrasonic sensor communication. The microcontroller sends a triggering signal to the ultrasonic sensor to start measuring distance. When triggered, the ultrasonic sensor starts a time counter with 8 acoustic wave shots.

The ultrasonic sensor we use is a waterproof ultrasonic sensor (Detection range: 3-45 cm, Operating temperature: -15°C – 60°C, Reference angle: 60°, Response time: 100ms). It determines the distance to the target by measuring the time between sending and receiving the ultrasonic pulse. It is positioned in relation to the nozzle to completely capture the row spacing.

## Arduino Board

In the project, Arduino Leonardo will be used to control the system, sensor data, and control between the nozzle. It will operate the solenoid valve on the nozzle. It is a microcontroller board based on Atmega32u4. It has 20 digital input/output pins (7 can be used as PWM output, 12 as analog input), 16Mhz crystal, micro USB socket, power socket, ICSP connector, and reset button. The board contains everything necessary for the microcontroller to operate. It can easily be connected to a computer via a USB cable and can be powered by an adapter or battery.

## MOSFET Module

The MOSFET module is a device used to control high-power devices with low power signals from Arduino or similar microcontrollers. Directly controlling high-power consuming devices like a solenoid valve with Arduino pins can exceed the limits of Arduino and cause damage (max. 20 mA). The MOSFET module is used as an intermediate component to safely control such high-power devices with Arduino. The module converts the low-power signal generated by the microcontroller into a high-power signal, allowing us to safely perform high-power tasks such as opening and closing a solenoid valve. In the project, a MOSFET module (33x24 mm; 10g; 3.3VDC, 5VDC) was used to enable the solenoid valve to execute open/close signals from the Arduino board. The module contains an IRF520 MOSFET circuit element.

## Solenoid Valve

A solenoid valve (24 V / 50 Hz, Input Current: 0.41 A (9.9 VA); Continuous Current: 0.23 A (5.5 VA)) has been used in the system for the control of the spray nozzle. Technical specifications of the solenoid valve:

Rain Bird 100 HV Solenoid Valve 1" BSP (32 mm) 24 Volt,

Pressure: 1.0-10.3 bar,

Flow rate: 0.05-6.82 m$^3$/h,

Height: 11.7 cm, Length: 11.2 cm, Width: 7.9 cm,

Temperature: Up to 43°C water temperature; up to 52°C ambient temperature,

24 VDC 50/60 Hz Solenoid,

Maximum Surge Current: 0.250 Amp,

Rated Current: 0.143 Amp,

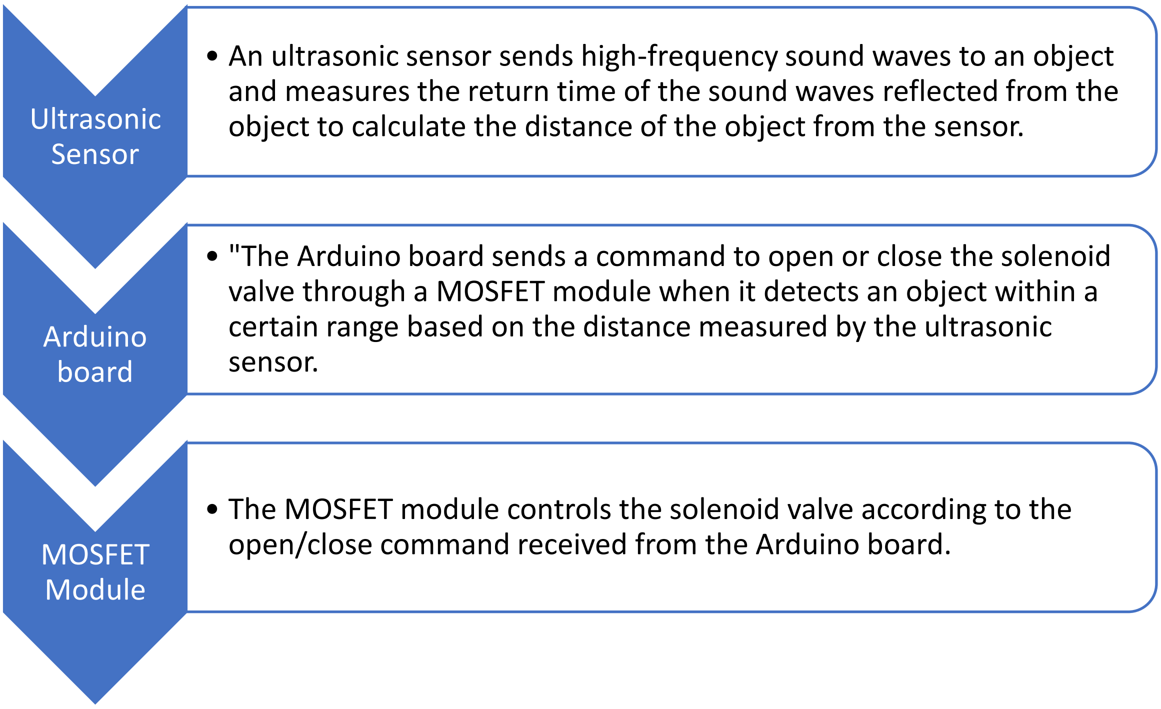
Coil Resistance: 555 Ohm.

## Spray Nozzle

A flat fan spray nozzle (Teejet XR11006) with a 110-degree spray angle has been used. The spray nozzle is mounted 40 cm behind the sensor as shown. Commonly used in sunflower agriculture and suitable for 1-4 bar pressures, this nozzle has a low drift risk and good surface coverage value with a 100-degree spray angle. The optimum height of the nozzle is 65 cm, and its flow rate under 3 bar pressure is stated as 2.37 l/min in the catalog.

While placing ultrasonic sensors and a spray nozzle on the vehicle, the spray angle, the distance between two wheels, the inter-row distance, sensor detection speed, and solenoid valve response times were considered in the planning. Accordingly, the track width of the carrier vehicle has been set at 94 cm, fitting the sunflower inter-row distance of 70 cm (Süzer, 2023). The height of the spray nozzle has been determined to be 80 cm. It has been sized appropriately.

In accordance with these parameters, the relationship between the detection time of the solenoid, the spraying time, and the approximate advancing speed of the operator was evaluated, and the control system was coded to spray 1 second later. For this purpose, the spray nozzle has been mounted 40 cm to the rear.



- An ultrasonic sensor sends high-frequency sound waves to an object and measures the return time of the sound waves reflected from the object to calculate the distance of the object from the sensor.
- "The Arduino board sends a command to open or close the solenoid valve through a MOSFET module when it detects an object within a certain range based on the distance measured by the ultrasonic sensor.
- The MOSFET module controls the solenoid valve according to the open/close command received from the Arduino board.

**Figure 3. The process steps in the electronic control unit.**

The designed system operates following the process flow seen in Figure 3. Accordingly, the ultrasonic sensor sends high-frequency sound waves to an object and measures the return time of the sound waves reflected from the object to calculate the distance of the object from the sensor. The Arduino board sends a command to open or close the solenoid valve through a MOSFET module when it detects an object within a certain range based on the distance measured by the ultrasonic sensor. The MOSFET module controls the solenoid valve according to the open/close command from the Arduino board and performs the spraying.

The height of weeds detectable by the sensor was examined in a laboratory setting. The detection system successfully identified weeds that were 50 mm or taller. Additionally, leaf density is an important factor that needs to be determined by the sensor.

## 2.2. Methods

The placement of ultrasonic sensors and spray nozzles on the carrier was planned by considering factors such as spray angle, distance between two wheels, row-to-row distance, sensor detection speed, and solenoid valve response times. Accordingly, the track width of the carrier cart was set at 94 cm, matching the sunflower row spacing of 70 cm (Süzer, 2023). The height of the spray nozzle was determined to be 80 cm, appropriately measured for these conditions.

Accordingly, the response time of the solenoid, spray timing, and the approximate forward speed of the operator were considered, and the control system was coded to spray 1 second after detection. For this purpose, the spray nozzle has been mounted 40 cm back.

The designed system operates by following the process flow shown in Figure 3. Accordingly, the ultrasonic sensor sends high-frequency sound waves to an object and measures the time it takes for the reflected sound waves to return, thus calculating the distance of the object from the sensor. The Arduino board, upon detecting an object within a certain range based on the distance measured by the ultrasonic sensor, uses this information to send a command to open or close the solenoid valve through a MOSFET module. The MOSFET module controls the solenoid valve according to the open/close command from the Arduino board, thus executing the spraying.

The height of weeds that can be detected by the sensor was examined in a laboratory setting. The detection system successfully identified weeds that were 50 mm or taller. Additionally, leaf density is an important factor that needs to be determined by the sensor.

## Trials

Trials were first conducted in the laboratory by placing objects ranging from 5 to 30 cm in height, with a minimum height of 5 cm, to check the sensor detections. Five random samples from each of the different heights were placed. In addition, the area moistened by the spray before and after it started and stopped was examined. Water-sensitive papers were used for analyses to determine spray characteristics in the trials.

Field trials were conducted in a sunflower field planted with 30 cm spacing on the row and 70 cm between rows. Clean water was used in all the trials. The trials were conducted with three repetitions. Before the application, a count was conducted to determine the density of weeds, and the types of weeds present were identified.

The trials were conducted using water-sensitive papers (WSP, 26 × 76 mm, Novartis, Syngenta Crop Protection, Basel, CH) as the sampling surfac(Özyurt & Celen, 2022) As seen in Figure 4, the water-sensitive papers were placed on sunflower plants, weeds, and empty spaces. In the trials, all the weeds in the row were identified, and three water-sensitive papers were positioned on these weeds. Thus, whether spraying was done on the weeds, on the sunflower plants, and the spray characteristics such as droplet diameters were analyzed and interpreted.

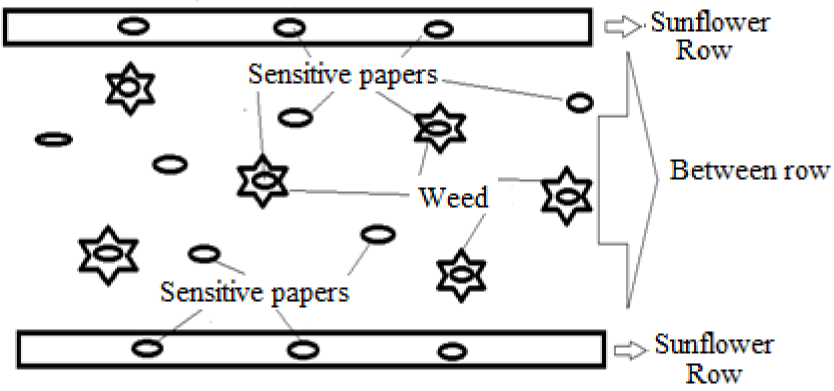


**Figure 4. Location of the water-sensitive papers**

The droplets collected on the water-sensitive papers were scanned using a scanner (with a resolution of 1176x1176 pixels) and transferred to a computer. The scans were analyzed using the DepositScan program to calculate droplet characteristics (Zhu et al., 2011). DepositScan is a suitable analysis program that can quickly assess the distribution of spray deposits on water-sensitive paper, even under fieldwork conditions, allowing for the on-site evaluation of spray quality (Zhu and Sciarini, 2010). It can calculate droplet size distribution ($Dv_{0.1}$, $Dv_{0.5}$, and $Dv_{0.9}$), the percentage of the selected area covered (%), the analyzed image area (Image Spot Area), individual droplet sizes (Actual Diameter), and the total number of droplets.

As a control group, the same backpack sprayer was used and compared in spraying conducted by mounting on the back.

## 3. RESULTS AND DISCUSSION

### 3.1. Laboratory trials

The prototype was designed and produced as described in the materials and methods section. Figure 6 shows the image of the electronic control circuit.

**Figure 6. Images related to the designed electronic control circuit**

**Table 1. Pre-Trials**

| Plant height between rows (cm) | Average wetting area ($cm^2$) |
|---|---|
| 5 | 180 |
| 10 | 191 |
| 15 | 187 |
| 20 | 190 |
| 25 | 175 |
| 30 | 180 |
| 35 | 189 |

In preliminary trials conducted in the Lab, the prototype recognized and sprayed on all objects of different heights placed in front of it. The ultrasonic system started spraying as soon as it detected artificial plants and continued spraying for 1 second. It continued spraying when it detected plants side by side. During spraying, the spray nozzle dispensed 2.45 liters per minute. The wetting area formed during spraying was measured and is given in Table 3. Upon examining the wetting areas, it was generally observed that an area of 90x20 cm² was wetted. In all applications, the forward speed was maintained constant at 0.32 m/s.

### 3.2. Fields trials

When evaluating the average wetted area, the importance of field applications became evident as it necessitated an assessment of success in terms of pesticide consumption. In the application made with this backpack sorayer, spraying was done over the entire area between the rows (along 200 meters). In the traditional application, a total of 20-20-20.5 liters of liquid was sprayed respectively in 505-509-508 seconds during three repetitions. In classical applications, an average of 82% of the tank was used over 200 meters.

**Figure 7. Machine operation during field trials**

In the spraying trials conducted using the prototype, plants shorter than 5 cm (3 in total) were not detected over 200 meters, while all higher plants (26 in total) were recognized and sprayed. A total of 2.1-2.0-2.0 liters of liquid was sprayed respectively in 525-509-510 seconds during three repetitions. The driving speeds varied depending on the operator's usage. In the applications performed with the prototype, a maximum of 8.4% of the tank was used. According to these results, consumption was reduced by 73.6%. If we add to this the reduction in costs arising from labor, fuel consumption, and maintenance and repair expenses for long-term operation, it means that production costs have been reduced by at least 73.6% in terms of savings. The types and numbers of weeds in the trial area are shown in Table 4.

There has been no unnecessary spraying between the rows. However, droplets were detected on the sampling surfaces placed on the rows. This could be attributed to drift, which occurred depending on the nozzle type and height. This issue will be resolved with a new arrangement.

**Table 4. Detected weed species and densities (number/m2) in the trial area**

| Weeds | Family | Number of weed |
|---|---|---|
| Chenopodium album | Chenopodiaceae | 5 |
| Echinochloa cruss-galli | Poaceae | 3 |
| Convolvulus arvensis | Convolvulaceae | 3 |
| Xanthium spinosum | Compositae | 12 |
| Sinapis arvensis | Brassicaceae | 3 |
| Centaurea solstitialis | Asteraceae | 1 |
| Setaria verticillata | Poaceae | 1 |
| Lactuca serriola | Asteraceae | 1 |
| **Total** | | **29** |

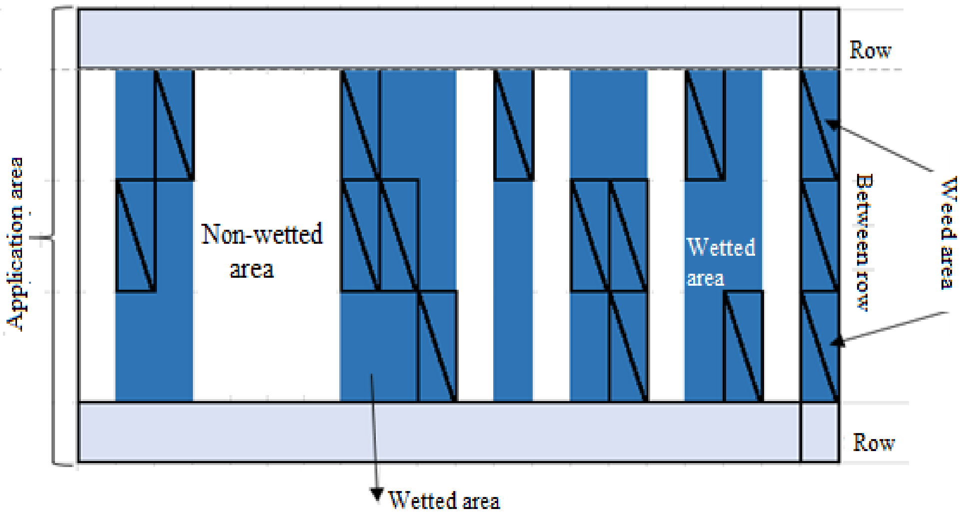


**Figure 8. Representative representation of the wet and non-wetted areas during field trials**

The machine sprayed by detecting the sensor 6 times for each repetition along a total of 200 meters of rows. It sprayed the same areas by carrying the same plants each time. During the application, it sprayed for 1 second, but the spraying continued depending on the detected plants during this time. As seen in Figure 16, there were multiple plants during the detection and spraying period.

### 3.3.Droplet Measurements

As explained in the methodology section, water-sensitive papers were placed on all plants seen in rows and between rows to determine the droplet characteristics of the spraying. Additionally, it was investigated whether the spraying reached the correct places. All measurements were performed in applications conducted for 3 repetitions.

In the measurement and analysis results obtained using the prototype, $Dv_{0.1}$ , 144 µm; $Dv_{\mathbf{0.5}}$, 284 µm; and $Dv_{0.9}$, 544 µm were obtained for the samples on the plants between rows. In addition, the surface coverage value was 78.1%. In the samples taken on the plants in rows, $Dv_{0.1}$, 151 µm; $Dv_{\mathbf{0.5}}$, 212 µm; and $Dv_{0.9}$, 276 µm were determined, and the surface coverage value was found to be 51.2% (Fig.9). Changes in droplet size, especially those observed on the plants in rows, occurred due to the influence of wind after the applications.

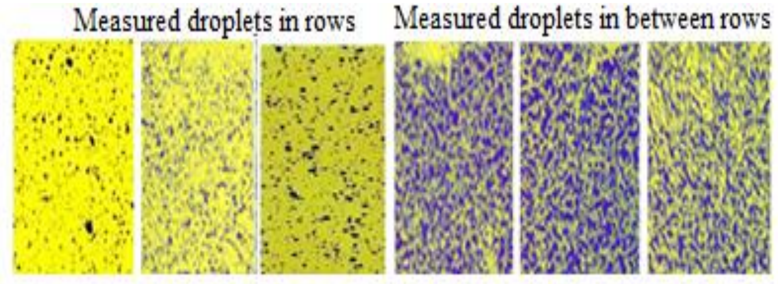


**Figure 9. Sampling surfeces**

In conventional applications, samples taken from the plants between rows resulted in $Dv_{0.1}$ of 185 µm, $Dv_{0.5}$ of 297 µm, and $Dv_{0.9}$ of 454 µm. Additionally, the surface coverage value was 89.4%. For the plants within rows, on the right side, $Dv_{0.1}$ was 168 µm, $Dv_{0.5}$ was 231 µm, and $Dv_{0.9}$ was 310 µm; on the left side, $Dv_{0.5}$ was 131 µm, $Dv_{0.5}$ was 216 µm, and $Dv_{0.9}$ was 247 µm. The surface coverage value was 65.2%. Changes in droplet diameter, especially those observed within rows, were influenced by wind after the applications (Fig 10). At this point, the operator's arm swinging during spraying caused the droplets to overlap, resulting in more droplets falling onto a unit area. Therefore, while the surface coverage value increased, it disrupted the droplet distribution.

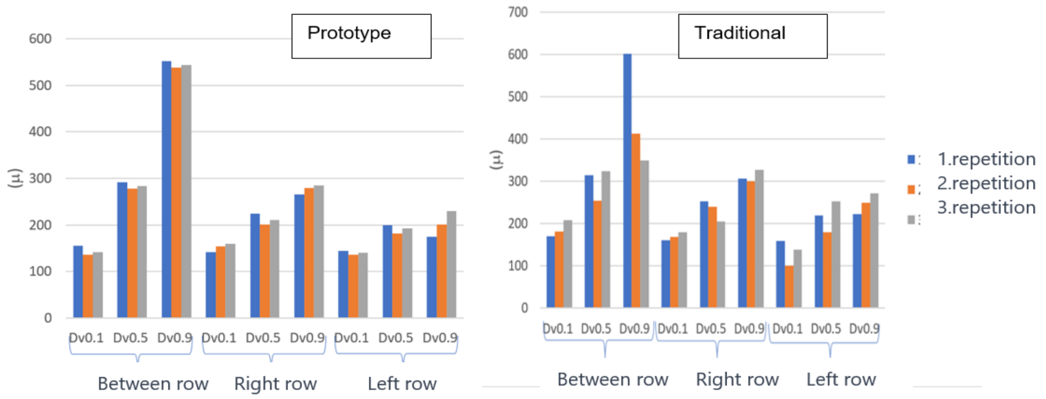


**Figure 10. Average droplet size values obtained in repeated applications on inter-row, right, and left rows as a result of spraying in the applications using the prototype and in the traditional application.**

## 4. CONCLUSION

In this project, a four-wheeled, hand-pushed vehicle sized to move between sunflower rows has been equipped with a gasoline-powered backpack atomizer. This setup detects weeds growing between sunflower rows using an ultrasonic system. A control system created with Arduino and MOSFET module has been used to control the spraying.

In the application area, the measurement results obtained using water-sensitive papers on and between the rows were compared with those from traditional backpack spraying applications. The effectiveness of the spraying was verified by checking where the spray reached.

As a result, the developed prototype accurately detected all plants larger than 5 cm and was able to spray all of them. However, spray liquid was also detected on plants in the rows where it should not have gone. This problem is seen as solvable by changing either the type of spray nozzle or its height. Additionally, compared to traditional methods, pesticide consumption was reduced by 73.6%, which is significant both economically and in terms of preventing environmental pollution.

Generally, in small-scale farming operations, weed control is done manually or with backpack sprayers, which requires intensive labor. Additionally, spraying pesticides over every area increases costs.

Ultrasonic sensors, a promising technology for future weed control in agriculture, can provide automatic and precise control in agricultural fields, increasing efficiency and offering a less harmful approach to the environment. Further research and development can enable wider use of this technology in the agricultural sector.

Our design is intended to be an affordable automation solution for small-scale farmers, unlike the high-cost sprayers designed for large farmers, which are often envied by smaller farmers. We believe farmers will prefer this machine as it not only eliminates the need to carry a heavy backpack sprayer but also reduces costs through less pesticide use. It's also important to enhance the familiarity and knowledge of small farmers with technology, a key task of Agricultural Machinery and Technology Engineering, and this gain should be valued.

As an important part of an environmentally friendly transformation in the agriculture industry, a successful sprayer has been designed and prototyped to improve traditional agricultural practices. The design has significantly reduced pesticide consumption by 86%, minimizing its negative environmental impact. Furthermore, the developed system enables spraying only in areas with detected weeds. This approach will reduce costs in agricultural pest control and prevent accidental damage to crops from chemicals.

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