Investigation of the effectiveness of AC/DC electric current as a weed control method using NDVI technique

Hasan Sahin

* Department of Mechatronics School of Technical Sciences, Harran University, Sanlıurfa, Turkey.

Abstract: Due to the negative environmental effects of herbicides, restrictions are imposed in many developed countries and the transition to alternative methods is encouraged. Upon these restrictions and prohibitions, non-chemical weed control methods have been started to be developed. One of these alternative weed control methods is the electric current method.

Background: Using multiple electrodes, the mortality rates were measured by exposing the plants germinated in laboratory conditions to AC and DC currents for different periods.

Objective: In this study, the effects of direct current (DC) and alternating current (AC) on the mortality rates of plants were investigated.

Keywords: Environment; Herbicide; Electrical/Mechanical Weed Control.

Methods: By comparing the NDVI (normalized difference vegetation index) values measured before and 1 week after the plants were exposed to electrical current, the effect of AC/DC on the mortality rate was determined.

Results: While mortality was between 11% and 17% for AC, mortality occurred at a rate of 31% in plants that had 300 volts DC applied for 350 s.

Conclusions: The degrees (r) of these relationships were 79.7% and 95.7%, respectively. According to these results, mortality rates increased as the voltage increased.

1. Introduction

Agricultural chemicals, which are widely used in agricultural activities, adversely affect the environment and human health. The difficulty of applying physical control methods has increased the interest in chemical (herbicide) use. Increasing demand for organic production and restrictions in many countries regarding the use of non-environmentally friendly agricultural chemicals has increased the interest in environmentally friendly weed control methods. Today, there are many new approaches to weed control, including artificial neural networks and robotic technologies (Monteiro et al., 2021). A sustainable and long-term strategy is required to minimize unwanted weeds grown in the agricultural field and increase crop yield (Brand et al., 2007). It is important to reduce the loss of weeds, which cause significant losses in many agricultural products such as sesame, by using non-chemical environmental methods (Lins et al., 2019). Studies have been carried out showing that the use of high technology in agricultural areas also reduces the frequency of weeds (Werle et al., 2021). Furthermore, widely using herbicides in agricultural weed control has caused undesirable plants to develop resistance to all kinds of herbicides. This has increased the orientation towards electrical/mechanical weed control methods in a electrical/mechanical weed management strategy (Khan et al., 2021). It is also important to know which method is more suitable for which weed control by comparing mechanical, physical and chemical weed control methods (Faleiro et al., 2022).

Some of the electrical/mechanical, weed control methods are the electric arc (current) method, the microwave method, hot steam, infrared, a pneumatic system, freeze-drying, and the laser cutting method, three sowing methods (Timossi et al., 2018). The electric current method is known to increase the heat of weed seeds (Nelson, 1996) in a short period, causing fading of the plant stem and leaves, and then the plants are completely biologically inactive (Wayland et al., 1975). After applying current, it is expected that the plant will weaken or mortality will occur because of the thermal effect caused by the electric current passing over the weed stem. It is seen as an alternative to chemical (herbicide) control methods because it does not leave any residue in the soil or plant (Mavrogianopoulos et al., 2000).

Alternative control methods that help determine the most economically feasible method have not yet reached the expected technological level due to incorrect comparisons (Coleman et al., 2019). New technologies, which cover alternative methods...
of combat, create the opportunity for field-specific weed management (SSWM) in agricultural areas by identifying undesirable plants individually and with a fast and correct intervention (Bakker et al., 2010). Site-specific control methods also allow for a fair and accurate comparison of electrical/mechanical weed control methods. Technological advances in artificial intelligence (AI) and robotics also have the potential to support ecological solutions in the IWM (integrated weed management) approach.

In a study carried out by passing electrical current at 100, 200 and 300 volts (AC) for 300, 420 and 540 seconds over one week old, germinated plants in contact with copper conducting electrodes, mortality rates were obtained between 70% and 100% (Sahin, Yalinkılıc, 2017). Scientific studies have emphasised that microwaves also have important potential in the control of various weed species (Hess et al., 2019; Sahin, 2014). However, the 2.45 GHz microwave technology used in this method has not yet reached a sufficient level in terms of economy and applicability. Besides, it is stated that the market power of these systems can be increased by saving more energy with microwave systems with weed detection technology (Brodie et al., 2012).

Electric current causes loss of cell viability in plant tissue in the areas exposed. This finding also conforms to the views of biophysicists about electrical damage to biological structures. In the electroporation method, the main target is to damage the cell membrane with a pulsed high voltage electric field. It causes damages the cell membrane and results in the death of the cell by collapsing the cell membrane. The electroporation technique applied to weed seeds is on the way to be a electrical/mechanical method for weed control (Lundensia, Persson, 2015).

A pulsed electrical current is more effective than the sinusoidal current in creating damage deep in the tissues of different plants (Ivanovich, Viktorovich, 2018). In one study, a Cockcroft-Walton type voltage multiplier capable of producing variable voltage for the variable load was used. The voltage multiplier provides the voltage needed for varying plant density without any additional circuits, processors, or controllers (Rona et al., 2019). It is an important fact that low DC voltages, such as 8–16 volts, increase plant vitality and quality (Gogo et al., 2016). Insufficient voltages used to kill weeds can also cause the weeds to grow and multiply by not adversely affecting them.

In experimental studies on electrical/mechanical weed control methods, it is important to accurately determine the mortality rates of plants. As far as is known, the NDVI technique is used for the first time in this study to calculate the mortality rate of weeds. The normalized difference vegetation index (NDVI) is a widely used method in determining the growth and mortality rates of plants (Rodrigues et al., 2021). The NDVI, which is based on the technique of plants with green components to reflect the energy of near-infrared wavelength and to absorb the energy of a visible red wavelength, is also a widely used method to monitor the changes in forested and agricultural areas (Arjasakusuma et al., 2018). In remote sensing systems, green plants with high biomass activity highly reflect the near-infrared wavelength. With the help of MODIS NDVI images created using this technique, the viability/mortality rates of plants can be calculated (Spruce et al., 2019). The NDVI method is also used in forest areas to monitor tree mortality rates. The use of NDVI data is a potential alternative method for creating regional tree death maps. This method is also an auxiliary method in natural resource management, forest dilution, and environmental and urbanisation activities (Schinasi et al., 2019). In the study of the analysis of the relationship between urban foliage rate and infant mortality in Philadelphia, the NDVI images derived from processed satellite data were used (Crouse et al., 2017). A similar study (Pantazi et al., 2016) based on spectral reflectance differences, used NDVI data for the rapid and accurate determination of biodiversity and spectral properties by a machine learning (ML) method, which can distinguish crops and weed species. Research on remote sensing-based solutions is becoming more common (Turner et al., 2003; Çelik, Sönmez, 2013; Çelik, Karabulut, 2013; Khare et al., 2018).

The effects of herbicides on human and animals such as bees, birds, and fishes are known. Some herbicides like phenoxy group causes cancer. However, it is the most widely used herbicide. It has been stated that triazines are associated with breast cancer, while terbuthylazine causes lung cancer (Mladinic et al., 2012). Some side effects of herbicides are deaths in non-target organisms and changing in the structure of the ecosystem and species (Solomon et al., 2013).

As the harms of herbicides are revealed and environmental awareness of humans increases, interest in non-chemical weed control methods (Banaras et al., 2020) (especially electric current and microwave) will increase. In addition, it is a known fact that long-term use of some herbicides creates resistance in weeds, making the control even more difficult (Bonow et al., 2018).

As can be seen from previous studies, many studies have been conducted on non-chemical weed control methods. Especially in studies using electric arc and microwave, more experimental studies have been included. The aim of this study is to demonstrate the usability of electric current as a non-chemical method in weed control. However, it is to investigate how alternating current (AC) or direct current (DC) application has an effect on mortality rates in plants.

2. Material and Methods

Air conditioning cabinet: To germinate the plant seeds at 20–22 °C temperature and 60-70% humidity, a temperature, humidity, and light-controlled Laborteknik IK-300 air conditioning cabinet was used.
Speed controlled conveyor belt: In the study, to simulate the movement of the tractor, a moving belt with a Power Flex 4M motor drive, whose speed ranges between 0.0099 m/s (0.03564 km/h) and 0.156 m/s (0.5616 km/h) was used.

Vertical Type Multi-Electrode Tunnel: The electrode tunnel consists of two pieces of 40 cm × 50 cm copper plates, with 30 × 30 pieces of vertically mounted copper electrodes. An electrical circuit was created by connecting the positive (+) end of the voltage regulator to one of the copper plates and the negative (−) end to the other (Figure 1).

Voltage Regulator: The voltage regulator (power supply) used in the experiment can operate between 1 and 300 volts. The power supply was 1 phase input/1 phase output, 1 kVA power input voltage range: 130 V AC/260 V AC, with an output voltage sensitivity of 220 V AC ± 2%. The DC voltage required for the DC experiments was obtained by converting the AC voltage received from the voltage regulator to DC with the help of the bridge diode circuit (Figure 2).

NDVI (normalized difference vegetation index) Meter: NDVI values before the exposure of plants to electric current and 1 week after application were measured with the TRIMBLE Green Seeker handheld device shown in Figure 3. The emission wavelengths of the device are red 660 nm, 25 nm FWHM, near-infrared 780 nm and 25 nm FWHM, and the field of view of the device is 25 cm at 60 cm or 50 cm at 122 cm.

2.1 Experimental method:

In the electric arc method, which is applied by passing an electric current over the plant body, according to equation (1), the electrical energy is converted into heat because of the electrical resistance (R) of the plant (Vincent et al., 2001).

\[ E = \frac{V^2 T_e}{R_p} \]  

where \( E \) is the quantity of energy transferred to the plant body, \( R_p \) is the electrical resistance of the plant, \( T_e \) is the contact time of the electrodes to the plants, and \( V \) is the applied voltage to the plant body.

Equation (2) shows the effective contact time of the electrodes (Vincent et al., 2001).

\[ n_e = L W_{eff} D \]  

Here, \( n_e \) is the product of the number of plants that the electrodes contact instantaneously, \( L \) is the electrode length, \( W_{eff} \) is the effective electrode width and \( D \) is the product density (Vincent et al., 2001). The undesired plants damage because of the high temperature caused by the electric current pass through the plant body. In equation (3), the total load resistance \( R_L \) is equal to the sum of the resistance sums of each plant \( R_p \) and the ground resistance \( R_s \) (Vincent et al., 2001).

\[ R_L = \left[ \sum_{i=1}^{n} \frac{1}{R_p} \right]^{-1} + R_s \]  

**Figure 1** - Vertical type multi electrodes tunnel

**Figure 2** - A diode bridge AC/DC converter

**Figure 3** - Trimble GreenSeeker handheld NDVI meter device (Trimble, 2021)
Increasing the number of electrodes that contact plants instantaneously will require increasing the generator power to be used in the application at the same rate. In Equation 3 (Vincent et al., 2001), the $R_P$ value, which expresses the resistance of plants, varies according to plant age, plant type, amount of cellulose it contains, and plant morphology (Yudaev, 2019). The equation is transformed into equality (4) by accepting equal resistance for all plant species.

$$R_L = \frac{R_P}{n_c} + R_s$$

Under ideal conditions, the power produced by the transformer assumes that the weed plants have resistance values close to each other. If the energy loss caused by the transformer, the resistance can be neglected, then it can be expressed as in equation (5) (Vincent et al., 2001).

$$P = \frac{V^2}{R_L} = \frac{n_c V^2}{R_s + n_c R_s}$$

The plant density in the application area, will increase the total electrical resistance of the plants, but it can be neglected, as it is very small compared to the resistance of the soil. The power of the generator will be a function of the applied voltage and ground resistance as shown in equation (6).

$$P = \frac{V^2}{R_s}$$

### 2.2 AC and DC voltage application by using vertical type multiple electrodes

Barley seeds were germinated in forty 20 cm × 30 cm aluminium pots (to provide electrical conductivity), one of which is the control group and the other three are samples. All of the samples were kept in the air conditioning cabinet at about 20–22°C temperature, average 1,000–1,200 lux light, and 60–70% humidity during germination and after the experimental treatment. One week old, germinated barley was subjected to 110, 220 or 300-volts DC voltage with three replicates for 150, 250 or 350 seconds with a vertical type multiple electrode method. The maximum contact of the plants to the electrodes, which are vertically mounted into the tunnel with the help of a movable conveyor belt, was attempted. Before and after application, moisture, the temperature of the soil, and the electrical current passing over plants during application were measured. Then, the same process was repeated for AC current. Before and after application, the moisture, temperature of the soil and electrical current passing over plants during application were measured. The NDVI values of the vegetation were measured and recorded before and one week after the application of current.

### 2.3 Statistical Analysis

In calculating the sample width of this study conducted for investigation of the effect of AC and DC voltage application on mortality rates, the power for each variable was determined by taking at least 0.80 and a Type 1 error of 0.05. The Shapiro-Wilk ($n < 50$) test was used to see if the continuous variables in the study were normally distributed and nonparametric tests were applied because the mortality variable was not normally distributed, and the number of observations was low ($n = 9$).

The effects AC-DC voltage method were examined with two-way variance analysis. For the AC-DC voltage method, the Mann-Whitney U test was calculated in comparison to mortality ratios. The Kruskal-Wallis H test was calculated for comparing mortality rates according to voltage, and Bonferroni post hoc (multiple) comparison tests were used to determine different groups. Spearman’s rho correlation coefficients were calculated to determine the relationship between mortality rates, voltage level and AC-DC voltage type. The statistical significance level ($\alpha$) was taken as 5% in calculations and SPSS (IBM SPSS for Windows, Ver.24) statistical software was used for calculations.

### 3. Results and Discussion

As shown in Table 1, no death occurred in plants that applied 110-volts DC for 150 s, 250 s and 350 s. Negative values seen in the table in 110-volt DC applications show that there is germination in plants contrary to mortality. Similarly, in previous microwave weed control studies, an increase in germination rates was observed in short-term microwave applications (Sahin, 2014). However, in 220-volt and 300-volt applications, mortality rates varying between 10% and 31% were realized in each repetition. Mortality rates increased as the duration of exposure to electric current increased. Average mortality rates were highest in 220-volt and 300-volt applications for 350 seconds.

Experimental studies conducted have the potential to make the electric current method an energy-saving tool in weed control (Yudaev, 2019). It was stated that, “the low DC voltages such as 8-16 volts increase the plant vitality and quality” (Gogo et al., 2016). Insufficient voltages used to kill weeds can also cause the weeds to grow and multiply by not adversely affecting them.

In Table 2, the results of the experiment performed by applying AC voltage to the plants are given. Similar to the DC voltage results, an average of 5% increase in the germination rate of the plants was recorded in the repetitions of 110-volt applied for 150 s, 250 s and 350 s. In 200-volt and 300-volt applications, the mean recurrence mortality for the same durations was approximately 15%.

In Table 3, mortality rates obtained when 110-volt, 220-volt and 300-volt AC-DC voltages are applied to plants are compared. It was observed that there
Table 1 - In vertical type multi-electrode method, current change and mortality rates in three replicates at 110, 220 and 300 DC voltage

| Voltage DC | Current(mA) min-max | Time(s) | Temperature ($T_s-T_i$) | Soil moisture | Plant density | NDVI$_1$ | NDVI$_2$ | Mortality |
|------------|---------------------|---------|-------------------------|---------------|---------------|----------|----------|-----------|
| 1-110      | 2-16.4              | 150     | 20-19                   | 75            | 0.560         | -        | -        | -1        |
| 2-110      | 3-19.13             | 250     | 20-20                   | 70            | 0.550         | 0.64     | 0.65     | -2        |
| 3-110      | 3-19.90             | 350     | 21-20                   | 78            | 0.580         | 0.64     | 0.66     | -2        |
| 1-220      | 2-108               | 150     | 20-19                   | 80            | 0.565         | 0.62     | 0.52     | 10        |
| 2-220      | 2-100               | 250     | 21-21                   | 77            | 0.585         | 0.63     | 0.48     | 15        |
| 3-220      | 2-128               | 350     | 21-20                   | 75            | 0.590         | 0.61     | 0.50     | 11        |
| 1-300      | 3-236               | 150     | 21-20                   | 73            | 0.580         | 0.64     | 0.47     | 17        |
| 2-300      | 2-221               | 250     | 23-21                   | 76            | 0.570         | 0.61     | 0.44     | 17        |
| 3-300      | 2-252               | 350     | 23-20                   | 81            | 0.550         | 0.66     | 0.35     | 31        |
| Control    |                     | 74      |                         |               | 0.590         |          |          | -7        |

DC: Direct current, mA: mili amper, NDVI: Normalized Difference Vegetation Index

Table 2 - In vertical type multi-electrode method, current change and mortality rates in three replicates at 110, 220 and 300 AC voltage

| Voltage AC | Current(mA) min-max | Time(s) | Temperature ($T_s-T_i$) | Soil moisture | Plant density | NDVI$_1$ | NDVI$_2$ | Mortality |
|------------|---------------------|---------|-------------------------|---------------|---------------|----------|----------|-----------|
| 1-110      | 2-49.53             | 150     | 21-20                   | 65            | 0.550         | 0.67     | 0.69     | -2        |
| 2-110      | 15-40               | 250     | 20-19                   | 66            | 0.580         | 0.68     | 0.74     | -6        |
| 3-110      | 18-39.50            | 350     | 20-20                   | 63            | 0.590         | 0.64     | 0.57     | -7        |
| 1-220      | 2.5-83.40           | 150     | 20-19                   | 62            | 0.575         | 0.62     | 0.49     | 13        |
| 2-220      | 1.6-90              | 250     | 20-21                   | 60            | 0.565         | 0.61     | 0.47     | 14        |
| 3-220      | 2.7-10.50           | 350     | 20-19                   | 65            | 0.595         | 0.50     | 0.39     | 11        |
| 1-300      | 2.6-182             | 150     | 21-20                   | 63            | 0.585         | 0.69     | 0.58     | 11        |
| 2-300      | 2.3-135             | 250     | 22-21                   | 61            | 0.570         | 0.64     | 0.50     | 14        |
| 3-300      | 3-200               | 350     | 22-20                   | 62            | 0.560         | 0.52     | 0.35     | 17        |
| Control    |                     | 64      |                         |               | 0.550         | 0.61     | 0.65     | -4        |

DC: Direct current, mA: mili amper, NDVI: Normalized Difference Vegetation Index

Table 3 - Comparison of mortality rates according to AC-DC method and voltage

| voltage | Median | Mean  | Std. Dev. | Min.  | Max.  | Median | Mean  | Std. Dev. | Min.  | Max.  | *p.  |
|---------|--------|-------|-----------|-------|-------|--------|-------|-----------|-------|-------|------|
| 110 volt | -6.00  | -5.00 | 2.65      | -7.00 | -2.00 | -16^b  | 0.58  | -2.00     | -1.00 | 0.105 |      |
| 220 volt | 13.00  | 12.67 | 1.53      | 14.00 | 10.00 | 12.00^c | 2.65  | 10.00     | 15.00 | 0.058 |      |
| 300 volt | 14.00  | 14.00 | 3.00      | 17.00 | 11.00 | 21.00^d | 8.50  | 17.00     | 31.00 | 0.102 |      |

*p. 0.058 0.026

Method: Voltage Interaction “p-value=.221” (two-way analysis of variance)

* Significance levels according to Mann-Whitney U test results →
** Significance levels according to Kruskal-Wallis Test results ↓

a,b,c: Bonferroni Post Hoc shows the difference between Voltage Types according to multiple comparison test
was no statistically significant difference between the mortality results of AC and DC voltage applied for the same durations for 110-volt (p > 0.05). In the 220-volt and 300-volt applications, higher mortality rates were obtained compared to the 110-volt applications. However, the difference here is due to the voltage values (p < 0.05). In other words, the application of AC or DC voltage did not significantly affect mortality rates for low voltages.

On the other hand, when using the DC method, a statistically significant difference was observed between the mortality rate observed according to voltage (p < 0.05). In other words, the level of the mortality rate was affected by the voltage level in the DC method. Here, 110 V and 300 V groups were different from each other. For the 220-volt and 300-volt AC/DC levels, mortality rates increased as the voltage increases.

Table 4 shows correlation analysis results between mortality rate and voltage and duration are given separately for AC-DC methods. According to this result, a statistically significant positive correlation was observed between mortality rate and volts in both AC and DC methods (p < 0.05). The degrees (r) of these relationships were 79.7% and 95.7%, respectively. According to the results, mortality rates increase as the voltage increases. Despite that, for AC and DC methods, no statistically significant correlation was observed between mortality rate and voltage (p > 0.05).

Figure 4 shows the mortality rates occurring at 110, 220 and 300 volts in AC and DC voltage applications with a vertical type of multi-electrode method. As shown in Figure 4, the highest mortality rates were obtained from 300 volts DC level (mean of three recurrences %22).

Figure 5 shows the mortality rates of AC/DC voltage methods for 150 s, 250 s and 350 s periods. As can be seen from Figure 5, the highest mortality rate was obtained as %30 in the application with DC voltage and 350 s duration.

Figure 6 shows the average mortality rates in the AC and DC voltage methods. Mortality rates in the DC voltage method were relatively a little higher than the AC voltage applications.

Figure 7 shows the mortality rates that occurred in AC and DC voltage applications for 150, 250 and 350 seconds. There was an increase in mortality rates as the voltage application time increases.

![Figure 4](image1)

![Figure 5](image2)

![Figure 6](image3)

![Figure 7](image4)

**Table 4** - Correlation analysis results between “Mortality rates” and “Voltage” and Time”, separately in AC-DC Methods

| Volt | AC   | DC   |
|------|------|------|
|      | r    | r    |
|      | p    | p    |

| Time (s) | AC   | DC   |
|----------|------|------|
|          | r    | r    |
|          | p    | p    |

*p < 0.05; **p < 0.01; r: Spearman’s rho correlation coefficient
As mentioned above, as seen in previous studies, low voltage or short-term microwave exposure can sometimes lead to increased germination in plants. In the vertical multi-electrode method in 110-volt DC recurrence, in contrast to mortality, there is an average 1.67% increase in germination (Wang et al., 2020). In the 110-volt AC application, an average of 5% germination rate increase was observed (Hess et al., 2018). Close results were also obtained in the microwave weed control method. A higher rate of germination was observed than the control group, which was not exposed to microwaves (Sahin, 2020; Sahin, 2014; Nelson, 1996).

As it is known, temperature, which is one of the factors necessary for seed germination, will accelerate germination up to a certain level and will restrict seed germination at higher levels (Lippmann et al., 2019; Desta, Amare, 2021). The results show that a statistically significant positive correlation was observed between mortality rate and volts in both AC and DC methods (p < 0.05). The degrees (r) of these relationships were 79.7% and 95.7%, respectively. According to the results, mortality rates increase as the voltage increases. Despite that, for AC and DC methods, no statistically significant correlation was observed between mortality rate and voltage (p > 0.05).

The results also show that the mortality rates in (220 and 300 volts) DC voltage methods are relatively higher than the (220 and 300 volts) AC voltage applications. Among mortality rates of AC/DC voltage methods for 150 s, 250 s, and 350 s periods, the highest mortality rate was obtained in the application with (220 and 300 volts) DC voltage and for 350 s duration (17% and 31% respectively). For 150, 250, and 350 seconds, there was an increase in mortality rates as the voltage application time increases in both AC and DC volts. It can also be said that the mortality rates in the DC voltage method were relatively higher than the AC voltage applications (Sahin, 2020).

In this study, a stepped power supply with a maximum output of 300 volts was used. The effectiveness of the method increases by keeping the voltage constant and increasing the application time. However, the results show that when the appropriate voltage is applied, considering the plant density and plant growth level, it has the potential to be used against all kinds of weeds.

Since this study was carried out in laboratory conditions, it was applied by obtaining a maximum voltage of 300 volts through the regulator using 220 volts, which is the mains voltage. As understood from the results, high voltage and current values will increase the success rate in weed control. Parameters such as weed age, root and stem structure, type and soil moisture are other factors affecting the efficiency of the method.

4. Conclusions

According to the results obtained in the study, to obtain higher efficiency in weed control with electric

![Figure 6](image1.png)  
**Figure 6** - The change of mortality rates according to the AC/DC method

![Figure 7](image2.png)  
**Figure 7** - Mortality rates depend voltage application time in both AC/DC method
current or microwave, it is necessary to know the physical, chemical and biological properties of the plant to which the current will be applied, as well as the plant dielectric properties.

The results obtained in the study show that AC/DC electric current has the potential to be used as a "weed control method", provided that direct current and voltage intensity are selected. It is thought that the data obtained in the study will help researchers who will work on this subject. It is expected that non-chemical alternative methods in weed control need more research and take more place on the agenda of relevant stakeholders.

References

Arjasakusuma S, Yamaguchi Y, Nakaji T, Kosugi Y, Shamsuddin SA, Lion M. Assessment of values and trends in coarse spatial resolution NDVI datasets in Southeast Asia landscapes. Eur J Rem Sens. 2018;5(1):1-15. Available from: https://doi.org/10.1016/j.ejremsens.2018.05.015

Bakker T, Bontsema J, Muller J. Systematic design of an autonomous platform for robotic weeding. J Terramec. 2010;47(2):63-73. Available from: https://doi.org/10.1016/j.jterra.2009.06.002

Banaras S, Javid A, Shoab A. Non-chemical control of charcoal rot of urd bean by Sonchus oleraceus application. Planta Daninha. 2020;38:1-10. Available from: https://doi.org/10.1590/S0100-835820203800100044

Bonov JL, Lamego FP, Andres A, Avila LA, Teló GM, Egewarth K. Resistance of echinochloa crus-galli var. mitis to imazapyr+ imazapic herbicide and alternative control in irrigated rice. Planta Daninha. 2018;36:1-11. Available from: https://doi.org/10.1590/S0100-835820183600100028

Brand J, Yaduraju NT, Shivakumar BG, Murray L. Weed management. In: Yadav SS, McNeil DL, Stevenson PC. Lentil. Berlin: Springer; 2007. p. 159-72.

Brodie G, Ryan C, Lancaster C. Microwave technologies as part of an integrated weed management strategy: a review. Int J Agron. 2012;2012:1-15. Available from: https://doi.org/10.1155/2012/636905

Çelik M, Karabulut M. [Monitoring the effects of rainfall conditions on pistachio (Pistacia vera L.) biomass activity and pheno- logical characteristics using remote sensing data]. Tur Cog Derg. 2013;[60]:37-48. Turkish.

Çelik M, Sonmez M. [An examination and monitoring of the changes of the agricultural conditions in Kızıltepe district by using MODIS NDVI data]. Marm Cog Derg. 2013;[27]:262-81 Turkish.

Coleman GR, Stead A, Rigter MP, Xu Z, Johnson D, Brooker GM et al. Using energy requirements to compare the suitability of alternative methods for broadcast and site-specific weed control. Weed Technol. 2019;33(4):1-18. Available from: https://doi.org/10.1017/wet.2019.32

Crouse DL, Pinault L, Balram A, Hystad P, Peters PA, Chen H et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. Lancet Plan Health. 2017;1[7]:e289-97. Available from: https://doi.org/10.1016/S2542-5196[17]30118-3

Destá B, Amare G. Paclobutrazol as a plant growth regulator. Chem Biol Technol Agric. 2021;8(1):1-15. Available from: https://doi.org/10.1186/s40538-020-00199-z

Faleiro EA, Lamego FP, Schaederl CE, Valle TA, Azevedo EBD. Individual and integrated methods on tough lovegrass control. Ciec Rural. 2022;52(9):1-8. Available from: https://doi.org/10.1590/0103-8478cr20210409

Gogo EQ, Huygens-Keil S, Krimlowski A, Ulrichs C, Schmidt U, Opjio A. Impact of direct-electric-current on growth and bioactive compounds of African nightshade (Solanum scabrum Mill.) plants. J App Bot Food Qua. 2016;89:1-8. Available from: https://doi.org/10.10573/jjabfq.2016.089.007

Hess MC, Buissen E, Mesléard F. Soil compaction enhances the impact of microwave heating on seedling emergence. Flora. 2019;259. Available from: https://doi.org/10.1016/j.flora.2019.151457

Hess MCM, Wilde M, Yavercovski N, Willm L, Mesléard F, Buissen E. Microwave soil heating reduces seedling emergence of a wide range of species including invasives. Restor Ecol. 2018;26(Suppl.2):S160-9. Available from: https://doi.org/10.1111/rec.12668

Khan N, Ray RL, Sargani GR, Ihtisham M, Khayyam M, Ismail S. Current progress and future prospects of agriculture technology: gateway to sustainable agriculture. Sustainability. 2021;13(9):1-31. Available from: https://doi.org/10.1016/j.acta.2021.7054201943000819

Khare S, Latifi H, Ghosh SK. Multi-scale assessment of invasive plant species diversity using Pléiades 1A, RapidEye and Landsat-8 data. Geocarto Inter. 2018;33(7):681-98. Available from: https://doi.org/10.1080/01038478.2018.1289562

Lipsmann R, Babben S, Menger A, Delker C, Quint M. Development of wild and cultivated plants under global warming conditions. Current Biol. 2019;29(24):R1326-38. Available from: https://doi.org/10.1016/j.cub.2019.10.016

Author’s contributions

SH: design of the electrode tunnel, all experiments, preparation of the manuscript according to the journal writing rules, and editing works.

Acknowledgements

The author would like thanks to Engineers of GAP Agricultural Research Institute, for their technical support.

Funding

This research received no external funding.
Lundensia AS, Persson B. Destruction of seeds from Sinapis Alba, var. Emergo with 50 mM Ca2+ and high voltage pulses. Acta Scientiar Lund. 2015;2:1-14.

Mavrogianopoulos GN, Frangoudakis A, Pandelakis J. Energy efficient soil disinfestation by microwaves. J Agri Enq Res. 2000;75(2):149-53. Available from: https://doi.org/10.1006/jaer.1999.0492

Mladinic M, Željezic D, Shaposhnikov SA, Collins AR. The use of FISH-comet to detect c-Myc and TP 53 damage in extended-term lymphocyte cultures treated with terbuthylazine and carbofuran. Toxicol Lett. 2012;211(1):62-9. Available from: https://doi.org/10.1016/j.toxlet.2012.03.001

Monteiro AL, Souza MF, Lins HA, Teófilo TMS, Barros Júnior AP, Silva DV et al. A new alternative to determine weed control in agricultural systems based on artificial neural networks [ANNs]. Field Crops Res. 2021;263. Available from: https://doi.org/10.1016/j.fcr.2021.108075

Nelson SO. A review and assessment of microwave energy for soil treatment to control pests. Transact ASAE. 1996;39(1):281-9. Available from: https://doi.org/10.13031/2013.27508

Pantazi XE, Moshou D, Bravo C. Active learning system for weed species recognition based on hyperspectral sensing. Bios Eng. 2016;146:193-202. Available from: https://doi.org/10.1016/j.biosystemseng.2016.01.014

Rodrigues TF, Cunha FFD, Silva GHD, Condé SB, Silva FCDS. Water use of different weed species using lysimeter and NDVI. Adv Weeds Sci. 2021;39:1-10. Available from: https://doi.org/10.51694/AdvWeedSci/2021;39:00004.

Rona SA, Valverde B, Souza DTM, Coutinho Filho SA. Weed inactivation device. United States patent US20200205395A1. 2019

Sahin H, Yalnıkılç M. Using electric current as a weed control method. Eur J Eng Res Sci. 2017;2(6):59-64. Available from: https://doi.org/10.24018/ejers.2017.2.6.379

Sahin H. Investigating the effect of single and multiple electrodes on mortality ratio in electric current weed control method with NDVI technique. J Fac Eng Arc Gazı Univ. 2020;35(4):1973-84. Turkish. Available from: https://doi.org/10.17341/gazimndfl.698307

Sahin H. Effects of microwaves on the germination of weed seeds. J Bios Eng. 2014;39(4):304-9. Available from: https://doi.org/10.5307/JBE.2014;39;4.304

Schinasi LH, Quick H, Clougherty JE, Roos AJ. Greenspace and infant mortality in Philadelphia, PA. J Urb Health. 2019;96(3):497-506. Available from: https://doi.org/10.1007/s11524-018-00335-z

Solomon KR, Dalhoff K, Volz D, Van Der Kraak G. Effects of herbicides on fish. In: Tierney KB, Farrell AP, Brauner CJ, editors. Fish physiology: organic chemical toxicology of fishes. Vol. 33. Amsterdam: Academic; 2013 p. 369-409.

Spruce JP, Hicke JA, Hargrove WW, Grulke NE, Meddens AJ. Use of MODIS NDVI products to map tree mortality levels in forests affected by mountain pine beetle outbreaks. Forests. 2019;10[9]:1-20. Available from: https://doi.org/10.3390/f10090811

Timossi PC, Texeira IR, Silva GF, Telles TF. Weed management with Urochloa ruziensis in three sowing methods. Planta Daninha. 2018;36:1-8. Available from: https://doi.org/10.1590/S0100-83582018360100060

Trimble Inc. Agriculture home. Westminster: Trimble; 2021[access Jan 09, 2021]. Available from: https://www.trimble.com/Agriculture

Turner W, Spector S, Gardiner N, Fladeland M, Sterling E, Steininger M. Remote sensing for biodiversity science and conservation. Trend Ecol Evol. 2003;18(6):306-14. Available from: https://doi.org/10.1016/S0169-5347(03)00070-3

Vincent C, Panneton B, Fleurat-Lessard F, editors. Physical control methods in plant protection. Berlin: Springer; 2001. p.175-8.

Wang H, Zhao K, Li X, Chen X, Liu W, Wang J. Factors affecting seed germination and emergence of Aegilops tauschii. Weed Res. 2020;60(3):171-81. Available from: https://doi.org/10.1111/wre.12410

Wayland J, Merkle M, Davis F, Menges RM, Robinson R. Control of weeds with UHF electromagnetic fields. Weed Res. 1975;15(1):1-5. Available from: https://doi.org/10.1111/j.1365-3180.1975.tb01088.x

Werle IS, Zanon AJ, Streck NA, Schaedler CE, Dalla Porta FS, Barbieri GF et al. Technology levels in cassava cultivation alter phytosociology of weeds. HortScience. 2021;56(7):787-94. Available from: https://doi.org/10.21273/HORTSCI15643-20

Yudaev IV. Analysis of Variation in Circuit Parameters for Substitution of Weed Plant Tissue under Electric Impulse Action. Sur Eng Appl Electrochem. 2019;55(2):219-24. Available from: https://doi.org/10.3103/S1068375519020157