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Research Article

Effects of Hot Water Obtained by Solar Energy on the Weeds *Convolvulus arvensis* L., *Setaria viridis* (L.) P. Beauv. and *Amaranthus retroflexus* L.

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Solar method,
Weed

Abstract: This study was carried out to determine the effect of hot water obtained by the solar method (solar energy) on the different plant growth stages of *Convolvulus arvensis*, *Amaranthus retroflexus,* and *Setaria viridis* species, which are problematic in agricultural areas. Hot water at a temperature of 98 °C, obtained using the solar method, was applied at 15:00 pm. The hot water was applied in two different doses depending on the driving speed (1st speed: 4 km h^{-1}, 2nd speed: 2 km h^{-1}) of the tractor. The application was carried out at three stages of plant growth (20, 40, 60 days old plants). According to the BBCH scale, these periods correspond approximately to GS:19, GS:40, and GS:60. In the results of the study; it was found that hot water application was more effective in the of GS:19 2 km h^{-1} (77%) to the aerial parts of *C. arvensis* and GS:19 2 km h^{-1} (68%) to the underground parts of *A. retroflexus*. In the hot water speed, it was observed that the 2nd speed (2 km h^{-1}) was more effective on weeds than the 1st speed (4 km h^{-1}).

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1. Introduction

Ever since the advent of agriculture, man has been confronted with weeds and has been dealing with them ever since. These plants, which we define as plants that grow where we do not want them and whose harm outweighs their benefit, are dominant in the habitat where they occur as long as they are not affected by biotic factors (humans, animals, plants, micro-organisms, etc.). Weeds, whether they are native to the area where they occur or of foreign origin, can easily adapt to different environments, from agricultural areas to pastures, from parks to archaeological sites, from wet habitats to sports fields, from fields and roadsides to railways (Uygur and Uygur, 2010). The damage caused by weeds is not only limited to areas of agricultural production but is also a problem in many non-agricultural areas. The damage patterns vary depending on where they grow. Weeds cause various problems in non-agricultural areas such as airports, railways, historic areas, flammable and explosive storage areas, open materials highway and railway embankments, around buildings, factories, industrial areas, industrial estates, pipelines, canal banks, and slopes. They are a source of fire hazard, especially when the weeds are dry (Jodoin et al., 2008; Tepe, 2023). Weeds give non-agricultural areas a poor appearance and a feeling of abandonment in the areas where they grow. It enlarges the openings or cracks from which it grows and thus poses a fire hazard and plant particles cause new weeds to grow, block signs on highways, and obstruct visibility on curves, leading to traffic accidents. By damaging the aesthetic appearance of the areas in which they are located, weeds shorten the life of historic monuments and sites (Rask, 2012; Gürbüz et al., 2019; Fracchiolla et al., 2022).

The types of weeds that are harmful vary between non-agricultural and agricultural areas, depending on the location. Many pathogens that damage crops allow insects and other creatures to thrive through weeds. (Tepe, 2023).

A widely used pesticide causes many health problems. A research of the scientific literature, it can be seen that pesticides are associated with a variety of negative health effects on humans, animals, wildlife, and the environment (Gürbüz and Koç, 2018; Kumar, 2023). Many methods are used to control weeds in agricultural and non-agricultural areas. Chemical control with herbicides is one of the most preferred methods because it is easy to apply and gives results in a short time. However, the harmful effects of these chemicals are increasing due to their excessive and unconscious use. To avoid these harmful effects, it is of great importance to use less environmentally harmful methods to control weeds. Thermal weed control is a non-chemical weed control method and can be used successfully in non-agricultural areas as well as in agricultural areas (Kitiş, 2010; Kitiş and Gürbüz, 2022).

Thermal weed control is the process of controlling weeds with high temperatures by transmitting heat energy from an energy source to the plant and increasing the temperature locally (Bauer et al., 2020). Here, methods such as flaming, hot water application, steam application, hot air, electric shock, microwave rays, infrared radiation, laser application, UV-rays, and freezing are used. Laser and optical radiation can be used effectively for thermal weed control, as the energy is absorbed by cellular pigments and water, converting light energy into heat (Zhang et al., 2024). In some of these methods (flaming, hot water application, steam application, etc.), heat energy is transmitted directly to the weeds, while in others (microwaves, UV rays, etc.) heat energy is transmitted indirectly (Rask and Kristoffersen, 2007).

Thermal weed control methods based on hot water are another alternative weed control method that causes less wear and tear on the treated surface than mechanical control methods such as hand pulling or hoeing. Many studies have shown that the above-ground parts of weeds can be destroyed by the application of hot water. The aim of the study was to use hot water to reduce the growth and spread of problematic weeds on hard surfaces without the use of herbicides. This includes the use of hot water generated by solar energy. The water is used to control weeds without harming the environment. On the other hand, this study was carried out to reduce the unnecessary use of herbicides and to prevent the possible development of resistance.

2. Material and Methods

This study was conducted in the greenhouse at Iğdır University Şehit Bülent Yurtseven Campus in 2018-2019. The aim of this study was to evaluate the effectiveness of solar-heated water as a non-chemical weed control method across various environments. To identify the most common problem weeds, surveys were carried out in non-agricultural areas (hard ground, pavements, asphalt and concrete).. As a result of the surveys, 2 dicotyledons (*Convolvulus arvensis* L.), (*Amaranthus retroflexus* L.) and 1 monocotyledon (*Setaria viridis* (L.) P. Beauv.) weed species with the highest density were used in the study.

2.1. Planting weed seeds in pots

The seeds of the weeds *C. arvensis, A. retroflexus,* and *S. viridis* were stored in a refrigerator at +4 °C to break the dormancy of the seeds for three months before use in the experiment. The soil medium was prepared by mixing garden soil, sand, and animal manure in a 1:1:1 ratio. In the experiment, 60 pots of 15x17 cm were used for each plant species were used. 10 seeds were planted in each pot to a depth of 5 mm. After planting, all pots were fertilized with 5 grams of Osmocote flower fertilizer at a 2:1:3 NPK ratio. When the plants grown from the seeds planted in the pots reached a size where they could compete with each other (3-4 leaves and 10 cm), they were thinned out leaving three plants in each pot. The thinned plants were watered regularly until they were 20 (1st GS/Growth Stages), 40 (2nd GS), and 60 (3rd GS) days old. The growth stages of the plants were determined according to the BBCH scale. These periods correspond approximately to GS:19, GS:40, and GS:60, each, according to the BBCH scale. GS:19 is the opening of 9 true leaves; GS:40 is the period in which the vegetative propagation organs begin to develop (rhizomes, stolons) and GS:60 is the period in which the first flowers open (single).

2.2. Hot water application on weeds

The experimental design used was replicated 4 times; the application was made at third growth stages (1st GS, 2nd GS, and 3rd GS), two different doses (1st dose and 2nd dose) and at 15:00 pm, De Cauwer et al. (2016) the solar heated water (Güney Sarıtaş, 2019) temperature was 98 ºC. The plants were placed in individual strips 10 cm apart, on the concrete floor, and hot water was applied before application, the air temperature was measured at 37 ºC using a digital thermometer. The hot water tank, which was specially designed for hot water application and can maintain the temperature of the water for 24 hours, was used by connecting the trailer to the back of the tractor. The hot water pump will operate with electricity and is supplied with electrical energy from the electrical outlet of the tractor. Water was sprayed at a constant pressure of 3 atm through the hot water pump attached to the outlet of the hot water tank. During the applications, the boom height was kept as close to the pot/plant surface as possible (5 cm) to prevent loss of water temperature. During the application of the amount of water per unit area, the tractor speed was 2 km per hour for the 2nd dose application and 4 km for the 1st dose application. The approximate water and energy amount of two different doses applied was 66.6 kJ m^{-2} (1.8 L m^{-2}) and 33.3 kJ m^{-2}(0.9 L m^{-2}), respectively. The plants were kept for one week after the hot water application.

2.3. Determination of the effects of hot water application on weeds

In order to observe the effect of the applied hot water on the above ground and below ground parts of the plants, the above ground parts of the plants were removed with scissors, and the root parts were removed from the pots, washed in 0.2 mm sieves and placed in paper bags. The paper bags brought to the herbology laboratory were placed in the oven and kept at 70 ºC for 24 hours and then removed. Then, the dry weights of the above ground and below ground parts of the plants were weighed with a precision scale and the data were noted. When hot water is applied to weeds, it rapidly raises the temperature of the plant cells, causing thermal shock. This sudden increase in temperature can rupture cell walls and denature proteins, leading to cell death. Depending on the weather, the plants start to dry out after a short time (Figure 1).

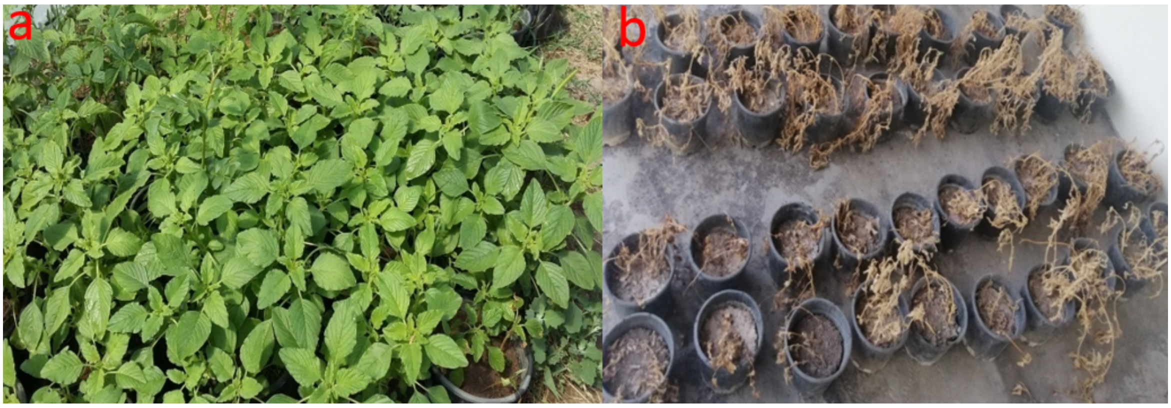


Figure 1. Visual comparison of plants before (a) and after (b) hot water application.

2.4. Statistical analysis

The obtained data were analyzed in the SPSS 20 statistical package program and subjected to analysis of variance (ANOVA). Differences between application doses and growth stages were determined by Duncan's multiple comparison test ($p<0.05$). Additionally, Microsoft Excel was used to show the percentage distribution of the findings.

3. Results

3.1. Determination of the effects of hot water application on weeds

In the study conducted, the results of the effects of hot water application on the above ground and below ground parts of the weeds *C. arvensis, S. viridis,* and *A. retroflexus* were evaluated by analysis of variance, and the differences between application doses and growth stages were determined by the Duncan multiple comparison test (P<0.05). The effects of different doses of hot water application on the growth stages of the above ground and below-ground parts of the *C. arvensis, S. viridis,* and *A. retroflexus* plants included in the experiment are presented in Figure 2.

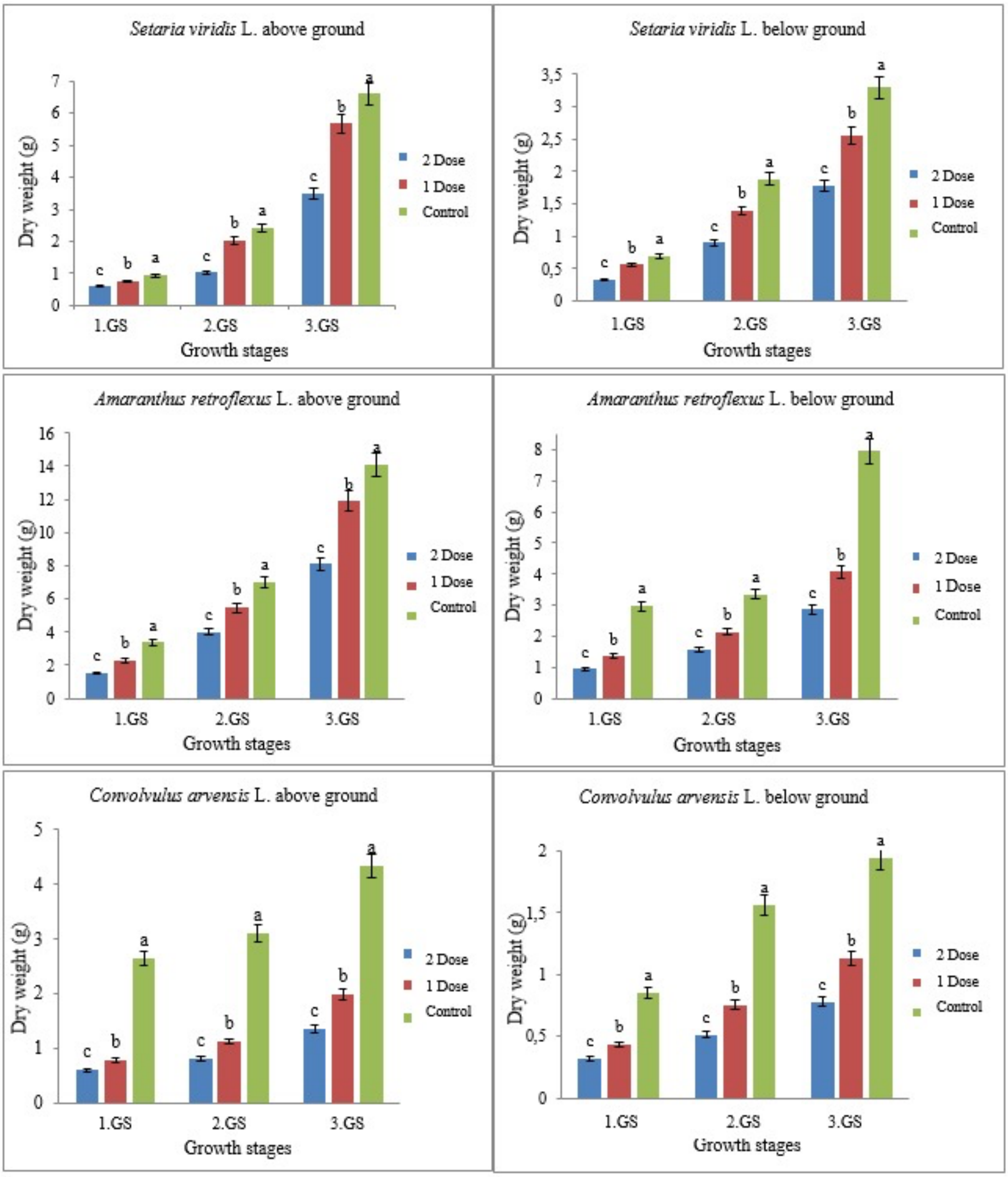


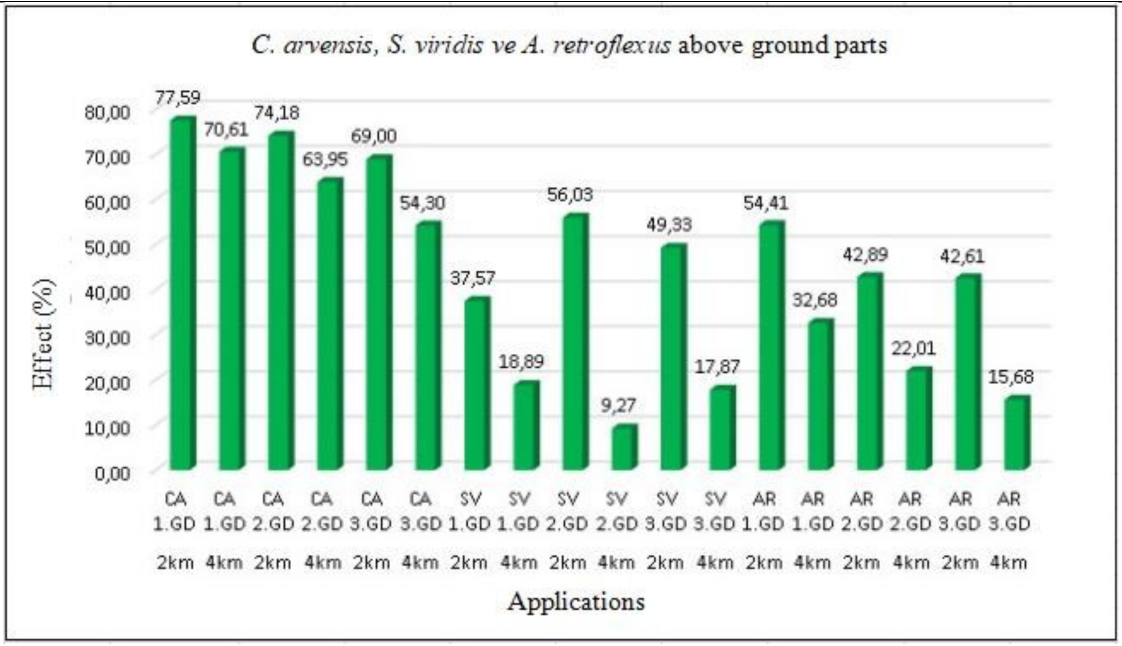
Figure 2. Effects of different doses of hot water application on the growth stages of the above ground and below ground parts of the *S. viridis, A. retroflexus,* and *C. arvensis.*

*Each growth stages were evaluated statistically within itself. Differences between means with the same letter are not significant at the 0.05 level. GS: Growth Stage.

As a result of the analyses, when we look at the growth stages for the above ground and below-ground parts of hot water application*, S. viridis, A. retroflexus,* and *C. arvensis* are the most effective in the first growth stage (1.GS), followed by the second growth stage (2.GS) and finally, it is also listed as the third growth stage (3rd GS). In general, it has been determined that 2 doses (66.6 kJ m^{-2}) are more effective than 1 dose (33.3 kJ m^{-2}). The same situation applies to the underground parts. When we compare the GS and doses of *S. viridis, A. retroflexus,* and *C. arvensis* aerial parts, 1st GS 1 dose applications show similar characteristics. As a result of the data obtained, it was seen that the decrease in the amount of dry matter was much more effective on the above ground and below ground parts of *C. arvensis*. As a result, the most effective one among the growth stages is the 1st GS, and it has been determined that 2 dose (66.6 kJ m^{-2}) application is more effective than 1 dose (33.3 kJ m^{-2}) application. Therefore, this comparison shows that hot water application is effective in controlling three weeds.

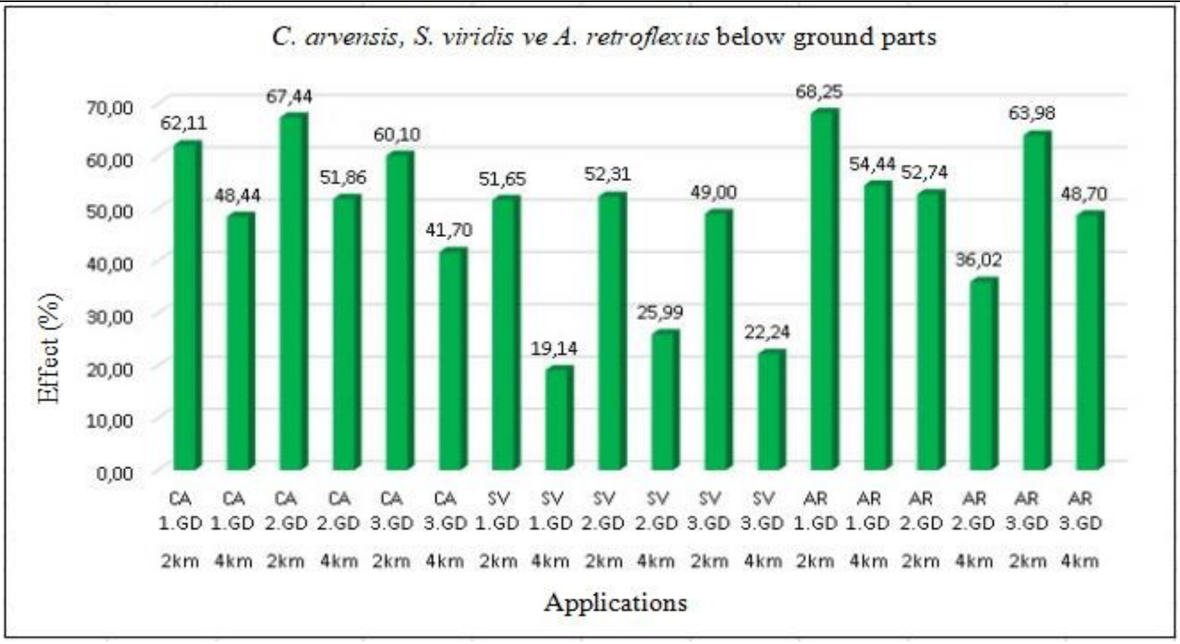
The percentage effect of hot water application on the dry weight of the above ground parts of the weeds is shown in Figure 3. The percentage effect of hot water application on the dry weight of above ground weed parts is shown in Figure 4.

The highest percentage effect of hot water application on the dry weight of the above ground parts of weeds is 77.59% on *C. arvensis* applied at a speed of 2 km in the 1st GS, and the lowest percentage effect is on GS, applied at a speed of 2 km in the 2nd GS with a rate of 9.27%. on *S. viridis* (Figure 3). The highest percentage effect of hot water application on the dry weight of the below ground parts of weeds is *A. retroflexus*, applied at a speed of 1st GS 2 km, with a rate of 68.25%, and the lowest percentage effect is 19.14% on *S. viridis*, applied at a speed of 1 st GS 4 km (Figure 4).



CA: *Convolvulus arvensis* SV: *Setaria viridis* AR: *Amaranthus retroflexus* GS: Grogwt Stages

Figure 3. Percentage effect of hot water application on the dry weight of above ground parts of weeds.



CA: *Convolvulus arvensis* SV: *Setaria viridis* AR: *Amaranthus retroflexus* GS: Growth Stages

Figure 4. Percentage effect of hot water application on the dry weight of the below ground parts of weeds.

4. Discussion and Conclusion

In our study, hot water was obtained using solar energy, whereas in a previous study (De Cauwer et al., 2015), hot water was obtained using diesel fuel. While the amount of energy delivered per unit area at the dose used effectively controls weeds, the number of applications can be reduced with an appropriate dose and excessive energy use can be avoided (Hansson and Ascard, 2002; De Cauwer et al., 2015). It is similar to the dosing practices we use. On the other hand, the growth stages of the weeds were also important for the effectiveness of the method (Hansson and Ascard, 2002; De Cauwer et al., 2015; Koç, 2019), and as the growth stages progresses, the amount of energy spent to control the weed also increases.

De Cauwer et al. (2015) obtained the best effect from the application of hot water at 98 ºC. It has been reported that broad-leaved plants have the highest sensitivity to hot water, while narrow-leaved plants have the lowest effect. In our study, it is similar in that hot water at 98ºC is used and *C. arvensis* is the most sensitive. De Cauwer et al. (2016) stated in their study that the plants they applied were more sensitive to hot water in the afternoon and that the sensitivity of plants to hot water was related to the change in leaf thickness and dry matter of the plants. In our study, it is parallel to our application of hot water at 15:00 in the afternoon.

In the research carried out by Hansson and Mattsson (2002), it was asserted that elevated temperatures generally resulted in a more significant reduction in the plant population. It is similar to our study. Similar to our study, Kristoffersen et al. (2008) used flame, steam, hot air, hot water, and brush applications in their study. They stated that the most effective application was hot water application. In our study, the air temperature was measured at 37 ºC with a digital thermometer before the application. Similar to our study, Hansson and Mattsson (2003) examined the effect of air temperature on the time when hot water was applied to the weed *Sinapis alba* L. in their study. Koç (2019) stated that hot water at 98°C obtained by thermal method for some weed species that cause problems in hard ground areas, the most effective result is at 15:00 and hot water is more effective on 1st GS. The results obtained in this study are parallel to the results we obtained in our study. While hot water application can control weeds, it has been reported that at much lower doses the seeds of *Impatiens glandulifera*, a problem in European countries, lose their ability to germinate. When comparing the effects of mowing and hot water in controlling *Impatiens glandulifera*, they reported that applying hot water at different stages of plant growth was more effective than mowing and that applying hot water in the early and late stages could save 50% of the water used (Oliver et al., 2020). The results of this study parallel the results obtained in our study. In a study by Bayat et al. (2017), they stated that since there are no problems such as chemical resistance in thermal weed control, all weeds are controlled when sufficient temperature is reached in plant tissues. They also stated that since there is sufficient solar radiation in our country, there is the potential to use solar heated water in many thermal methods. The results of these studies are consistent with what we observed in our study. It is important to use methods that do not harm the environment when controlling weeds. One of these methods, the application of hot water, uses heat as an alternative to harmful chemicals to control weeds. They stated that this method is effective in reducing fire hazards that may arise from the use of flame (Hansson and Mattsson, 2002). The aboveground parts of weeds can be controlled by applying hot water. In this respect, it is similar to our study. However, the amount of energy required for this process may be higher compared to the use of herbicides (Hansson and Ascard, 2002). Compared to chemical weed control, the reapplication time of thermal methods is shorter (Reichel, 2003; Kristoffersen et al., 2004; Rask and Kristoffersen, 2007; Kristoffersen et al., 2008). However, problems caused by the effects of herbicides can be prevented with thermal methods. It is also important because it gives much faster results than chemical control. They stated that hot water application causes less wear compared to mechanical methods such as hand pulling or hoeing in non-agricultural areas and is a different, non-chemical alternative method for weed control (Gürbüz et al., 2019; Koç, 2019; Güney Sarıtaş, 2019; Gürbüz et al., 2024). The results obtained in these studies are parallel to the results we obtained in the present study.

As a result of the analysis, when we look at the growth stages for above ground parts of *C. arvensis, S. viridis,* and *A. retroflexus* with hot water application, the most effective is the first growth stage (1st GS), followed by the second growth stage (2nd GS) and finally the third growth stage (3rd GS). In general, it has been determined that 2 doses are more effective than 1 dose. The same situation applies to the below ground parts. It has been determined that 2 dose application in the third growth stage (3rd GS) and the second growth stage (2nd GS) is more effective than 1 dose application. However, no difference was found between doses in the first growth stages (1st GS). As a result of the study, it was generally observed that when 98 °C hot water was applied in the third growth stages of the plants, there was a significant decrease in the dry weight of the above ground and below ground parts. By using thermal methods instead of chemical methods used against weeds in non-agricultural areas, weeds will be controlled and the wrong and unnecessary use of herbicides will be prevented. In short, the use of hot water can be recommended as an alternative solution to chemical weed control.

Further research is necessary to optimize the use of hot water for weed control in non-agricultural areas, focusing on different weed species, varying water amounts, and different temperature settings.

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