Agronomy Research **14**(1), 14–24, 2016

Use of thermal images for optimizing burner height, operating pressure, and burner angle of a weed flamer

S. Arslan[1,*], N. Tursun[2], F. Kurtulmuş[1] and D. Güleç[3]

[1]University of Uludag, Faculty of Agriculture, Department of Biosystems Engineering, TR 16059 Bursa, Turkey
[2]University of Inonu, Faculty of Agriculture, Department of Plant Protection, TR 44100 Malatya, Turkey
[3]University of Kahramanmaraş Sütçü İmam, Graduate School of Natural and Applied Sciences, Department of Biosystems Engineering, TR 46100 Kahramanmaraş, Turkey
[*]Correspondence: sarslan@uludag.edu.tr

Abstract. A two-meter wide prototype weed flamer was developed as a tool for thermal weed control. The weed flamer consists of an LPG tank, pressure regulator, back pressure valve, flow valves, and burners. The burner adjustments are flexible with height setting from 0 to 450 mm and flame angle setting from and 0 to 90°.The thermal camera images were studied at different heights (150, 200, 250, and 300 mm), burner angles (30 and 45°), and pressures (0.1, 0.15, 0.2, 0.25 MPa) to determine the best settings under stationary operating conditions. Based on thermal camera image results, it was found that the burner should be set at 200–250 mm with 0.2–0.25 MPa to obtain the highest temperatures and longest flames. The initial tests of the gas burning system were completed as a broadcast flaming machine and gas doses from 15 to 90 kg ha^{-1} were applied from 0.25 m above the ground at 30° flaming angle at 0.2 MPa. The dose-response curves of a weed (*Convolvulus arvensis* L.) were generated to determine the effectiveness of the weed flamer. *C. arvensis* could be controlled with gas doses from 40 to 82 kg ha^{-1} depending on the growth stage at 14 day after treatment (DAT). The theoretical field capacity of the 2 m wide flamer varies from 0.32 to 1.62 ha h^{-1} depending on the gas dose to be applied.

Key words: weed control, flaming, thermal image, dose-response, LPG.

INTRODUCTION

Controlling the weeds in arable lands is challenging due to complex nature of the weeds and their ability to sustain in different ways. In today's agricultural practices, the most efficient way to cope with weeds is to use herbicides, a common type of pesticides. However, the drawbacks of using pesticides are well known to humans, animals, and environment. The governments and the related organizations tend to put strong emphasis on reducing pesticides, urging researchers to develop alternative methods to reduce agricultural chemicals. One of the methods that can be technically applicable is flaming, a thermal method of weed control. The cost-effectiveness of the thermal methods was discussed in the literature and some researchers reported results in favor of weed flaming, particularly in organic farming (Parish, 1990; Ascard, 1995; Bond & Grundy, 2001; Rifai et al., 2003). The weed flaming was studied for both field crops (Pelletier et al., 1995; Seifert & Snipes, 1998; Ulloa et al, 2010), vegetable growing (Netland Set al., 1994; Wszelaki et al., 2007; Sivesind, 2010), and for disease control (Laguë et al., 1997; Mirzakhani & Ehsani, 2014). Flamers are also used in urban areas where pesticides are avoided (Rask et al., 2012; Raffaelli et al., 2013). Selective flaming can be an option particularly in areas where the labor is expensive for weeding (Sivesind, 2010).

Several researchers studied the technical and engineering aspects of a weed flamer. Knezevic et al. (2011) recommended that a research type weed flamer consists of a tank, flow safety valve, strainer, master solenoid valve, shut off valve, flow regulator, pressure gage, pilot solenoid valve, and burners. The performance of different flamers was studied (Lague et al., 1997) and a research flamer was developed by other researchers (Ascard, 1995; Kang, 2001; Knezevic et al., 2007).

The calibration of a flaming machine depends upon the working width and ground speed during the application (Kang, 2001). The speed affects the gas (propane or LPG) dose (kg ha^{-1}) applied in the field. The calibration may be done by measuring the gas flow rate at different pressures and choosing an applicable pressure to obtain sufficient gas flow rate that will provide gas doses from 15 to 90 kg ha^{-1} (Knezevic & Ulloa, 2007; Sivesind et al., 2009) or higher doses than 90 kg ha^{-1} (Kristoffersen et al., 2008).

The low propane doses require high ground speeds at a given pressure or gas flow rate. The ground speeds were reported from 1.0 to 7.5 km h^{-1}, however, an acceptable constant ground speed may be chosen in which case the pressure setting needs to be adjusted to provide the desired propane doses (Mutch et al., 2008; Ullua et al., 2010).

Different types of thermocouples were used by researchers for measuring the flame temperatures to develop the burners, optimize the adjustments, or determine the effect of flaming on weed control (Ascard, 1995; Laguë et al, 1997; Ascard, 2008; Mojžiš & Varga, 2013). However, flame images were not extensively utilized to study the heat variation behind the burner. The general objective of this study was to develop a weed flamer that can be used for surface and row flaming. The specific objective of the study was to use thermal camera images of the flames to determine the best operating conditions for the burner angle, burner height, and gas pressure and to use the flamer to obtain the dose-response curve of a given weed.

MATERIALS AND METHODS

Materials

An LPG burning system was developed in this study, which is the sub-system of the cultivator-flamer machine developed under a different project not reported in this paper. The gas burning system consists of an LPG tank, pressure reducing valve, a valve group to distribute the gas to the burners, and burners with a 1.5 mm gas nozzle. The LPG tank was designed with 1.7 MPa operating pressure and a burst pressure of 3.0 MPa. However, the gas pressure inside the tank was not greater than 1.0 MPa after being filled with LPG up to 80% of the theoretical tank capacity.

Chromium shafts were used as the carrier of the burners. The burners were also manufactured using chromium metal sheets.

A cultivator was used to integrate the gas burning system with mechanical unit. The tank was mounted on the cultivator frame and burners were mounted on a shaft that was attached to the rear bar of the cultivator. This part of the study was not included in this paper.

A thermal camera (Testo T885) was used to capture the flame images behind the tractor from the side view. For field tests, a weed species (*C. arvensis*) was selected to determine the applicability of the weed flamer for effective weed control.

Methods

First, the gas burning system was designed, which comprised a gas tank with 12 kg capacity to develop the burner with a 1.5 mm gas nozzle. The nozzle and the burner were tested at different pressures (0.05, 0.1, 0.15, 0.20, 0.25 MPa) to determine the flow rate of the nozzle as a function of pressure (Güleç et al., 2015). The flow rate of the nozzle was determined using gravimetric method by measuring the weight difference of the tank for a given time interval (60 s) using an electronic scale. These tests were replicated four times providing the pressure-flow rate characteristic of the nozzle, the width and the length of the flame obtained from the burner. LPG was used to burn in the system and the calibration of the burner was done by using the flame width of a single burner and the gas doses (15, 30, 45, 60, 75, and 90 kg ha^{-1}) to obtain the necessary ground speed of the flamer.

Then a 580 L capacity gas tank was built and mounted on a cultivator frame for the field operations. The gas burning system was modified to work with 8 burners with 0.25 m flame width for each burner, resulting in a 2 m wide working width for broadcast flaming. A hood was built and mounted over the burners to improve the efficiency of the flaming. The flamer can be used with or without the hood depending on field conditions during a specific application.

The angle of the flame (30° and 45°), the height of the burner (150, 200, 250, and 300 mm), and the pressure were varied to determine the best settings for flaming during the tests conducted under stationary conditions. The flame temperature values, the heat distribution behind the burner, and the flame lengthweremonitored using the thermal camera so that the height, the angle, and the operating pressure of the burner could be optimized.

Field tests were conducted to confirm that the weed flamer could be used to find the dose-response curves of a given weed species. For this purpose, *C. arvensis,* a common weed throughout the country, was chosen. The field trials were done in the walnut and mixed fruit orchards of İnönü University to obtain the dose-response curves of *C. arvensis* during hooded flaming. Based on the adjusted heights and pressure values found from thermal camera images, 0.25 m height, 30° flame angle, and 0.2 MPa gas pressure were set for field application.

The weed control rate was determined based on visual observations in the 1, 7, and 14 DAT with four replications at 2–4, 6–8, and 10–12 leaf stages. Log-logistic model was used to obtain the weed control rates (Streibig et al., 1993; Seefeldt et al., 1995) and the results were graphed using the dose-response curve statistic (Knezevic et al., 2007) added to the R program (R Development Core Team, 2006). The biological efficiency of flaming was determined by using control rates of 50%, 80%, and 90%.

RESULTS AND DISCUSSION

The weed flamer

The picture of the weed flaming machine developed in this study is given in Fig. 1. The system comprises a pressure release valve, pressure regulator, gas level indicator, and a charging inlet for LPG.

Figure 1. The weed flamer developed in this study.

The burners of the flamer were set equally spaced on the carrier shaft for surface flaming (Fig. 2a). The angle of each flamer with respect to the ground can be adjusted by rotating the burner shaft around the carrier shaft (Fig. 2b).

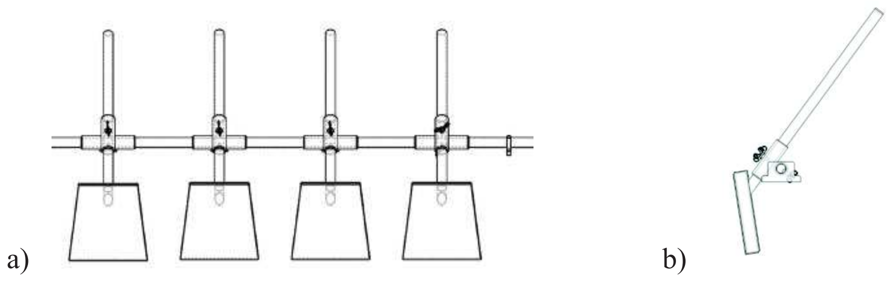
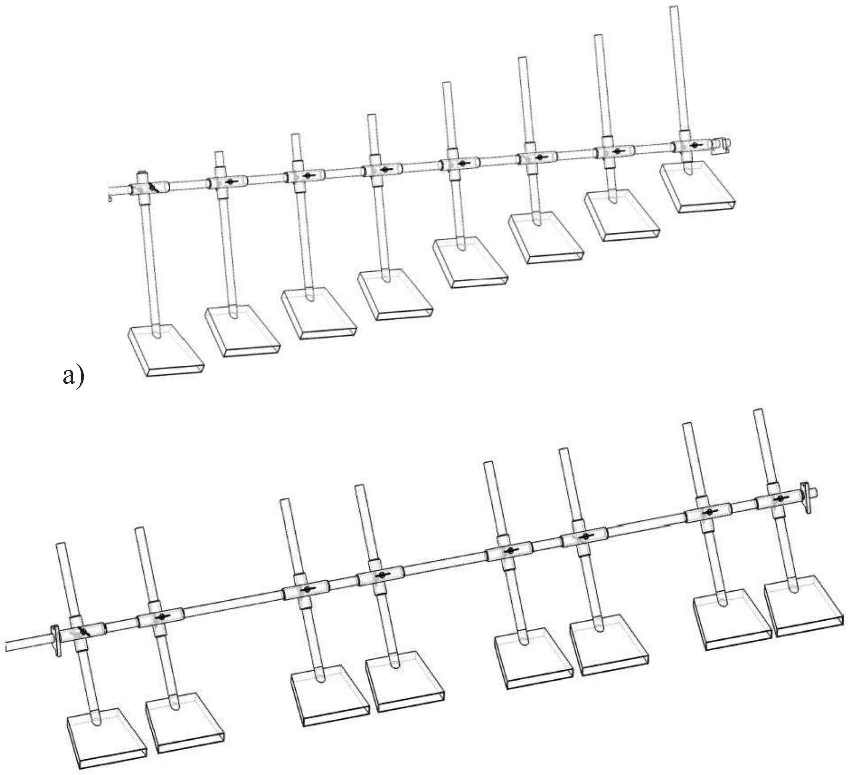


Figure 2. a) The carrier shaft and the burners, b) Angle of the burner set towards the ground.

The height of each burner can be adjusted separately by sliding the burner shaft up and down inside the vertical pipe of the apparatus that allows lateral and vertical movement of the burners (Fig. 3a). The burners could be grouped up with multiple numbers for band flaming or for row flaming (Fig. 3b).



a)

b)

Figure 3. a) Flexible height adjustment of burners, b) Spacing adjustment of burners.

The burners could be rotated on the vertical axis so that a burner faces to the sides to control intra-row weeds on the crop rows (Fig. 4). In such configuration, either two burners will face against each other or can be staggered with a small modification so that the flame could be directed towards the rows.

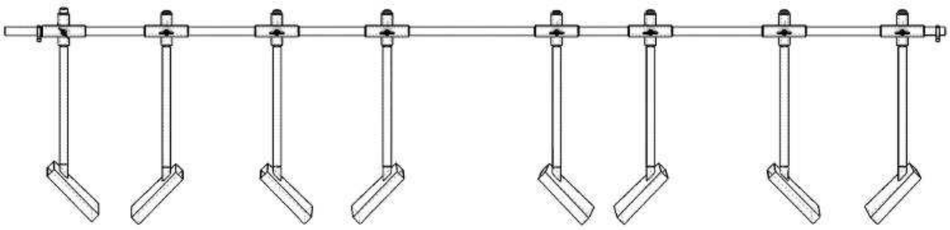
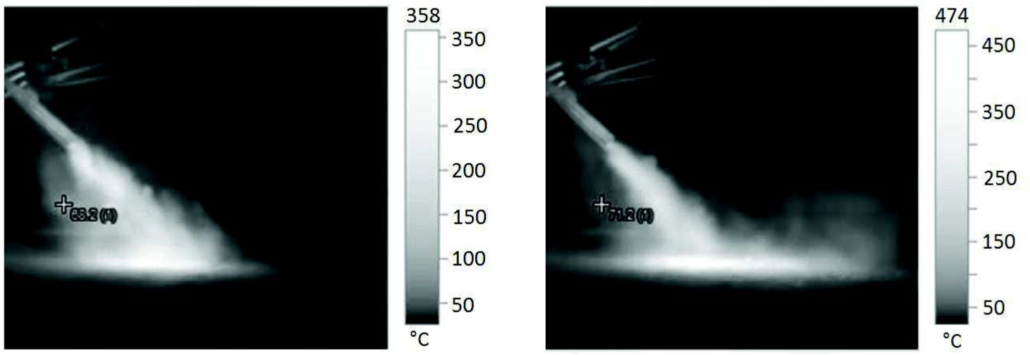


Figure 4. Rotating the burners towards row plants for intra-row flaming.

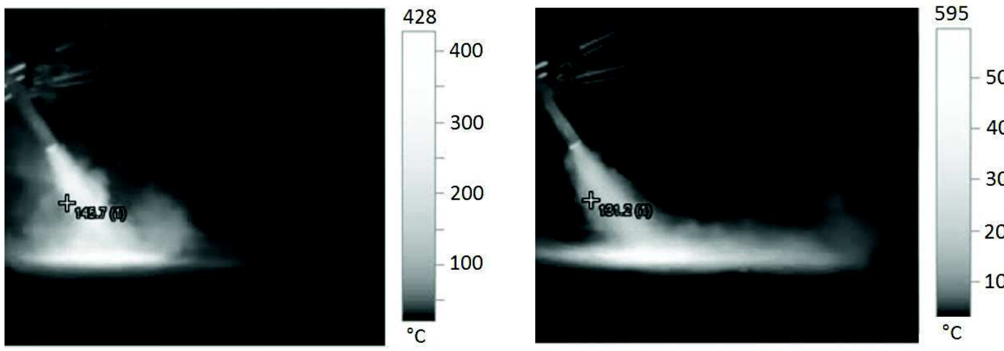
Thermal camera images

The thermal camera images at different gas pressures, burner heights, and burner angles were studied based on visual observations. The effect of burner angle and the gas pressure at a given burner height is given in Fig. 5. At a burner height of 300 mm and burner angle of 45° (Fig. 5a), the flame temperatures above the ground at 0.1 MPa were much lower (320 °C) compared to the temperature values (about 400 °C) at 0.25 MPa.

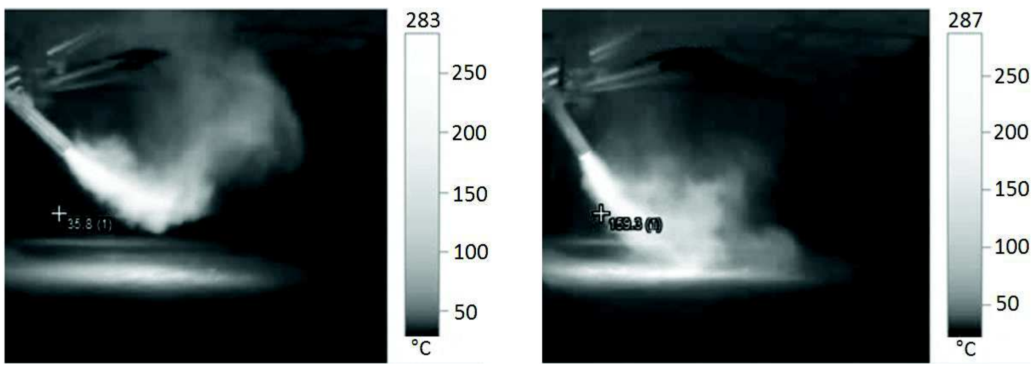
When the burner angle was set to 30° (Fig. 5b), the flame was better directed towards the ground and increased the temperatures approximately by 50 °C at both 0.1 and 0.25 MPa, compared to the burner angle of 45°. It was inferred that operating the gas burning system at low pressures and big burner height settings with 45° burner angle would not be efficient to obtain high temperature over the ground.



a) 45°, 0.1 MPa, 300 mm 45°, 0.25 MPa, 300 mm



b) 30°, 0.1 MPa, 300 mm 30°, 0.25 MPa, 300 mm

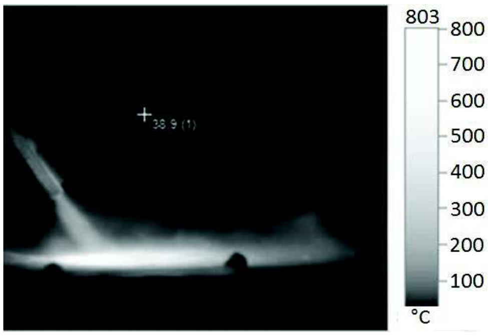


c) Wind effect. 45°, 0.1 MPa, 300 mm 30°, 0.1 MPa, 300 mm

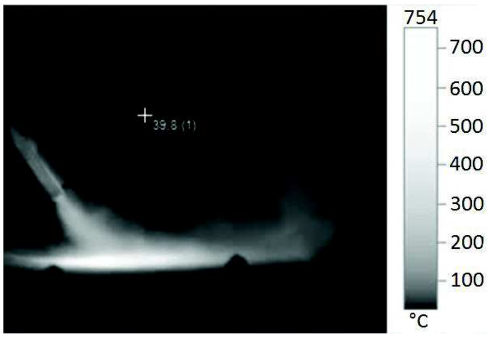
Figure 5. Effect of pressure on heat trace behind the burner at 300 mm height and 0.1 MPa pressure setting: a) at 45°, b) at 30° c) wind effect at 45° and 30°.

An image was also obtained when there was wind in the opposite direction of the flame angle at 0.1 MPa (Fig. 5c). The flame was significantly affected by the wind and was found to be weak to reach the ground at 45°. The same observation was made at the burner angle of 30° at 0.1 MPa (Fig. 5c) under the effect of wind speed of 0.5 to 1.5 m s^{-1}. It was concluded that the low gas pressure and increased burner height settings could not efficiently spread the heat over the ground under the field conditions, especially in the presence of wind in opposite direction. Based on the observations made above, the lowest gas pressure (0.1 MPa) and the greatest burner height setting (300 mm) were considered inefficient for weed flaming with the system developed in this study.

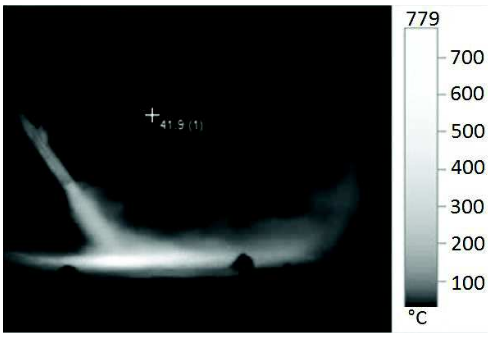
Lower temperature values were obtained over the ground when the burner height was set to 150 mm at both 45 and 30° flaming angles, compared to the burner height settings at 200 and 250 mm. Therefore, the images taken at burner height of 150 mm were not presented in the results. The more applicable burner heights to achieve high flame temperature and longer flame length were 200 and 250 mm at gas pressures of 0.2 and 0.25 MPa (Fig. 6).



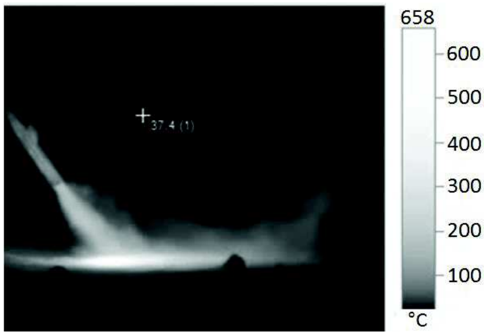
a) 30°, 0.25 MPa, 200 mm



30°, 0.20 MPa, 200 mm



b) 30°, 0.25 MPa, 250 mm



30°, 0.20 MPa, 250 mm

Figure 6. The flame patterns at 30° flame angle at different 0.25 and 0.2 MPa with 200 mm (a) and 250 mm (b) burner heights.

The flame length increased and was about 600 mm under 0.2 and 0.25 MPa. Also, the temperatures in Fig. 6 were greater, compared to Fig. 5, as shown on the temperature bars next to the images. The highest measured flame temperatures in Fig. 5 ranged from 280 to 590 °C depending on the burner and gas pressure settings whereas the greatest temperatures in Fig. 6 ranged from 650 to 800 °C. It was concluded that the gas pressures of 0.20 and 0.25 MPa with 200 and 250 mm heights could be used in field applications whereas the pressures of 0.1 and 0.15 MPa with 150 and 300 mm would not be effective.

It should be noted that the greatest temperatures on the temperature bars in Figs 5–6 relate to the spot temperature where the flame hits the ground, resulting from directing the flame on the same spot during the test. Therefore the flame temperatures over the ground were less than the hot spot temperature on the ground. In this study, the thermal camera images were helpful to see under which conditions the flame reached the ground and spread well over the ground by studying the side view of flame. The measured hot spot temperatures will probably not be exposed to the weeds under field conditions. These tests were conducted under stationary conditions to obtain the images, thus increasing the surface temperature during the experiments. Despite this poor representation of field working conditions, the images were helpful to determine the differences in flame shape behind the burner, providing useful data on the best combinations for the gas pressure, burner height, and burner angle settings.

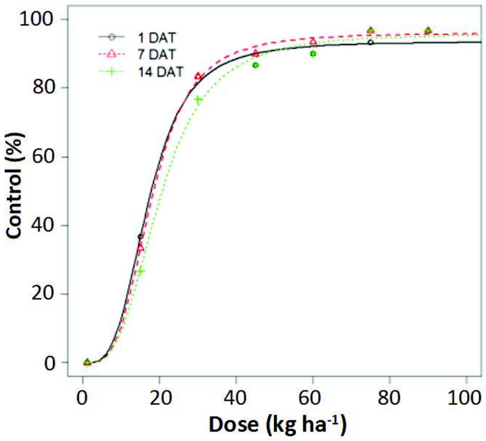
Storeheier (1994) used burner angles of 22.5°, 45°, and 67.5° at heights of 20, 40, and 60 mm with pressures between 0.12 and 0.25 MPa. The burner was suggested to be close to ground with angles between 22.5 and 45°. Also, it was found that the burner angle was not important as the height of the burner increased, according to Storeheier (1994). The current study agrees that the burner height defines whether the flame can reach the ground independent of the burner angle. At the burner height of 300 mm, the greatest height used in this study, the tested burner angles could not generate high temperatures on the ground. Ascard (2008) directed the burner towards the ground at 33°, 45°, and 90° (straight down) at a height of 10 cm from the ground and found that 33° provided the best weed reduction. In terms of burner angle setting, the findings of our study were similar to those of Ascard (2008), suggesting that the burner angle should be close to 30° rather than 45°.

Dose-response curves

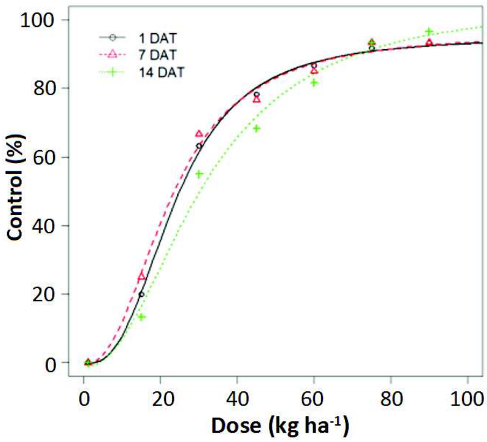
Among the four combinations of burner angle, gas pressure, and burner height given in Fig. 6, 0.2 MPa operating gas pressure and 250 mm burner height were chosen and six different gas doses (15, 30, 45, 60, 75, and 90 kg ha^{-1}) were applied in the field conditions to determine the control rate of the selected weed (*C. arvensis*). Fig. 7 shows the dose-response curves at three different growth stages at 1, 7, and 14 DAT.

The control rate of the weed in Fig. 7 improved with increased applied dose. The control rate increased rapidly with increasing gas dose at low doses from 20 to 40 kg ha^{-1}. Less than 80% control could be achieved at 1 DAT and 7 DAT with 40 kg ha^{-1}. At 14 DAT, the need for dose was much greater (about 80 kg ha^{-1}) for 80% weed control.

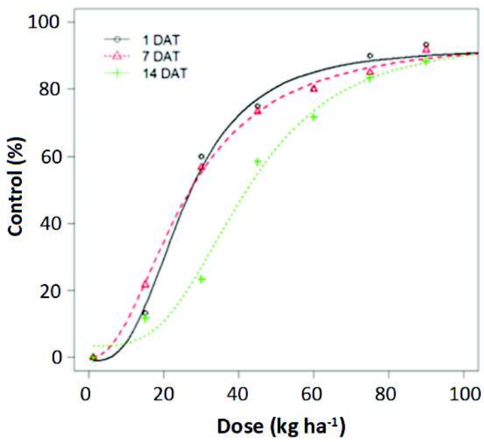
The doses applied in the field were similar to the doses used in previous studies (Knezevic & Ulloa, 2007; Sivesind et al., 2009) and were enough to control the weeds at different growth stages. Fifty per cent weed control rate was achieved with 17 to 20 kg ha^{-1} at 2–4 leaf stage whereas the dose requirement increased to 26 and 42 kg ha^{-1} at 10–12 leaf stage. For 90% control rate, dose ranges were about 38 to 40 kg ha^{-1} and 55 to 82 kg ha^{-1}, respectively at 2–4 and 10–12 leaf growth stages. Ascard (1995) controlled other weeds at 0–4 leaf stage at a control rate of 95% with 10–20 kg ha^{-1} propane dose and 100% with a propane dose of 20–50 kg ha^{-1}. Kang (2001) found that 40 kg ha^{-1} and greater LPG doses could control 80% of the weeds while 60 kg ha^{-1} dose achieved 90% weed control rate. The differences in the dose requirements compared to other studies may be attributed to the differences in weed species.



a) 2–4 leaf stage



b) 6–8 leaf stage



c) 10–12 leaf stage

Figure 7. Dose-response curves showing the control rates of *C. arvensis* as a function of gas dose at three different growth stages at 1, 7, and 14 day after treatment (1 DAT, 7, DAT, and 14 DAT).

Field capacity

Using the flamer width of 2.0 m and the ground speeds from 1.6 to 8.1 km h^{-1}, the theoretical field capacity of the machine was calculated to be 0.32 to 1.62 ha h^{-1} for the applied doses from 15 to 90 kg ha^{-1}.

In this study, an attempt was made to determine whether applicable operating conditions could be found by studying the thermal camera images of the flames using the side views during flaming in stationary operations. The temperature distributions of the flames showed that the differences in flame temperature and the length of the flame could be visually observed and compared.

CONCLUSIONS

The followings could be concluded as result of this study:

1. Flaming angle of 30°was better than 45°. Increased burner angle reduced the temperatures measured on the ground behind the tractor.
2. Low operating pressures (0.1 and 0.15 MPa) were not sufficient to generate high temperatures near the ground. Furthermore, in the presence of wind, the flame pattern distorted easily resulting in very poor heat distribution over the ground.
3. The best combinations of the pressure and burner height were found with 0.2–0.25 MPa and 200–250 mm, respectively.
4. Thermal camera images were helpful to determine inefficient operating conditions for the given gas nozzle and burner.
5. The field tests showed that a broadleaf weed (*C. arvensis*) could be controlled at 90% level with 40 kg $ha^{-1}$and 82 kg ha^{-1}at 14 DAT, respectively at 2–4 and 10–12 L stages at 0.2 MPa gas pressure at 250 mm burner height.
6. The theoretical field capacity of the weed flamer was calculated to be 0.32 ha h^{-1} for the greatest dose (90 kg ha^{-1}) and 1.62 ha h^{-1} for the smallest dose (15 kg ha^{-1}) applied in the field.

ACKNOWLEDGEMENTS. The authors would like to thank Turkish Scientific and Technological Research Council (TUBİTAK) for financially supporting the project no. 213 O 109. We appreciate the support of İnönü University for providing the experimental field. The workshop of the Biosystems Engineering Department was used at Kahramanmaraş Sütçü İmam University to develop the initial prototype, and Gemciler Tarım Makineleri Co cooperated in building the prototype used in the field experiments.

REFERENCES

Ascard, J. 1995. *Thermal Weed Control by Flaming: Biological and Technical Aspects*. PhD Dissertation, Germany.

Ascard, J. 2008. Flame weeding: effects of burner angle on weed control and temperature patterns. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science* **48**(4), 248–254.

Bond, W. & Grundy, A.C., 2001. Non-chemical weed management in organic farming systems. *Weed Research***41**, 383–405.

Güleç, D., Arslan, S. & Tursun, N. 2015. The use of different gas injectors for developing flame cultivator torches. *Journal of Agricultural Machinery Science* **113**, 231–237(in Turkish, English abstr.).

Kang, W.S. 2001. Development of a flame weeder. *Transactions of the ASAE* **44**(5), 1065–1070.

Knezevic, S., Dana, L., Scott, J. & Ulloa, S. 2011. Building a research flamer. Leaflet. University of Nebraska.

Knezevic, S., Streibig, J.C. & Ritz, C. 2007. Utilizing R software package for dose-response studies: the concept and data analysis. *Weed Technology* **21**, 840–848.

Knezevic, S. & Ulloa, S. 2007. Potential new tool for weed control in organically grown agronomic crops. *Journal of Agricultural Sciences* **52**(2), 95–104.

Kristoffersen, P., Rask, A.M. & Larsen, S.U. 2008. Non-chemical weed control on traffic islands: A comparison of the efficacy of five weed control techniques. *Weed Research* **48**(2), 124–130.

Laguë, C, Gill, J., Lehoux, N.& Péloquin, G. 1997. Engineering performances of propane flamers used for weed, insect pest, and plant disease control. *Applied Engineering in Agriculture* **13**(1), 7–16.

Mirzakhani, N. & Ehsani, R. 2014. Controlling citrus black spot (cbs) disease using both a flame bar and a sweeper attachment. *In Proc. ASABE and CSBE/SCGAB 2014 Annual International Meeting*, Paper Number: 141913496, pp. 7.

Mojžiš, M. & Varga, F. 2013. Effect of setting the parameters of flame weeder on weed control effectiveness. *Journal of Central European Agriculture* **14**(4), 1356–1363.

Mutch, D.R., Thalman, S.A., Martin, T.E. & Baas, D.G. 2008. Flaming as a method of weed control in organic farming systems. Michigan State University Extension Bulletin E-3038.

Netland, J., Balvoll, G. & Holmoy, R. 1994. Band spraying, selective flame weeding and hoeing in late white cabbage. Part II. *Acta Horticulture* **372**, 235–243.

Parish, S. 1990. A review of non-chemical weed control techniques. Biol. Agric. Hort. **7**, 117–137.

Pelletier, Y., McLeod, C.D. & Bernard, G., 1995. Description of sub-lethal injuries caused to the Colorado potato beetle by propane flamer treatment. *J. Econ. Entomol*. **88**, 1203–1205.

Raffaelli, M., Martelloni, L., Frasconi, C., Fontanelli, M. & Peruzzi, V. 2013. Development of machines for flaming weed control on hard surfaces. *Applied Engineering in Agriculture* **29**(5), 663–673.

R Development Core Team, 2006. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. http:// www.R-project.org.

Rask, A.M., Kristoffersen, P. & Andersen, C. 2012. Controlling grass weeds on hard surfaces: effect of time intervals between flame treatments. *Weed Technology* **26**(1), 83–88.

Rifai, M.N., Miller, J., Gadus, J., Otepka, P. & Kosik, L. 2003. Comparison of infrared, flame and steam units for their use in plant protection. *Res. Agr. Eng.* **49**, 65–73.

Seefeldt, S.S., Jensen, J.E. & Fuerst, E.P. 1995. Log-logistic analysis of herbicide dose response relationships. *Weed Technology* **9**, 218–227.

Seifert, S & Snipes, C.E. 1998. Response of cotton (Gossypium hirsutum) to flame cultivation. *Weed Technology* **12**(3), 470–473.

Sivesind, E.C. 2010. Selective Flame Weeding in Vegetable Crops. *PhD Dissertation*. McGill University, QC, Canada.

Sivesind, E.C., Leblanc, M.L., Cloutier, D.C., Seguin, P. & Stewart, K.A. 2009. Weed response to flame weeding at different developmental stages. *Weed Technology* **23**, 438–443.

Streibig, J.C., Rudemo, M. & Jensen, J.E. 1993. *Dose Response Curves and Statistical Models*. In: Streibig, J.C., Kudsk, P. (Eds.), Herbicide Bioassay. CRC Press, Boca Raton, FL, USA, 29–55.

Storeheier, K.J. 1994. Basic investigations into flaming for weed control. Acta Horticulturae **372**, 195–204.

Ulloa, S.M., Datta, A., Malidzab, G., Leskovsekc, R. & Knezevic, S.Z. 2010. Timing and propane dose of broadcast flaming to control weed population influenced yield of sweet maize (Zea mays L. var. rugosa). *Field Crops Research* **118**, 282–288.

Wszelaki, A.L., Doohan, D.J. & Alexandrou, A. 2007. Weed control and crop quality in cabbage [Brassica oleracea (capitata group)] and tomato (Lycopersiconly copersicum) using a propane flamer. *Crop Protection* **26**, 134–144.