Potential Use of Low Pressure Gas Nozzles for Surface Flaming to Control Weeds

Selçuk Arslan[1], Nihat Tursun[2], Duran Güleç[3]

***Abstract*—**Thermal weed control via flaming is usually achieved at propane (or LPG) gas pressures from 0.1 to 0.5 MPa, mostly near the middle or high end of the range. The objective of this study was to study the potential use of relatively low pressures (0.2-0.25 MPa) to build a surface flamer for weed control with a 1.5 mm gas nozzle. The current study attempts to determine the flame behavior using thermal camera images under field conditions. A research weed flamer with 2 meter working width (8 torches with 0.25 m flame width) was designed, built, and mounted on the hitch of an agricultural tractor. The side-view flame distribution was captured during broadcast flaming by using thermal camera images at different ground speeds (1.6 and 8.1 km h^{-1}), pressures (0.2 and 0.5 MPa), and torch heights (200 and 250 mm) with a flame angle of 30° to determine the best combination for the best flame distribution on the surface. It was determined that 0.2 MPa pressure could not be used at high speeds, especially when the flame is applied from 250 mm height. Increased pressure (0.25 MPa) improved the flame length and height over the surface. It was concluded that, with a low pressure gas nozzle, the torch height should not be greater than 200 mm if the pressure is set to 0.2 MPa. More images are necessary to study the 2D and 3D thermal maps from the rear side of the flaming machine to make better inferences.

***Keywords*—**Thermal weeding, weed flamer, flame length, pressure.

I. Introduction

FLAMING is a non-chemical weed control method, which can control a wide variety of weeds in arable lands [1]. Flame cultivation has received much of its attention in organic production systems although initial research studies focused on field cropping.

The flamers developed so far can be portable, semi-portable, pull types or hitched types. Different sizes in terms of working widths and tank capacities have been used in commercial flamers and research prototypes. Researchers have developed different types and sizes of the weed flamers, including tubular burners [2], 50 cm wide hand-pushed infrared burner [3], a self driven 75 cm wide infrared gas burner [4], and row flamers mounted on a tractor. Commercial flamers with bigger sizes and many different types are available in some countries.

Flaming mostly used for weed control to eliminate or reduce the herbicide use in plant production, however, research also focuses on controlling plant diseases [5]-[6].

In addition to the agricultural use, the flamers have urban and suburban use on hard surfaces as well. The flamers can be used instead of trimmers in mechanical weed control and may be less costly compared to the ordinary treatments in the urban areas [7].

If the purpose is to direct the flame to the intra-row weeds, there are two methods used for this purpose. The first one is to apply the flame over the plants and weeds together once the plants gain heat tolerance and the weeds are young enough to be affected by the applied dose. In this case the applications are similar to the surface spraying in chemical applications. The second method requires torches to be directed towards the roots of the plants so that the heating effect is limited to the growing plants while the intra-row weeds are flamed, preferably by cross flaming. In the second type of application the flaming angle to the vertical axis may need to be high to avoid applying heat to the leaves and stems of the plants.

The factors affecting the calibration of flamers are the pressure and the forward (ground) speed during operation. In order to obtain dose-response curves of the weeds, propane doses are applied in the range from 0 to 90 kg ha^{-1} and higher [8]-[9]. The pressures tested for developing or studying different types of torches range from 0.1 to 0.5 MPa [6]. The flame torch angles of 30-45 ºC provide the best efficiency in controlling the weeds.

The ground speed of the flamers is usually low, especially if the propane dose needs to be high. In flame weeding studies, ground speeds of 1.0-7.5 km h^{-1} are usually used depending on dose requirements. 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 [10]-[11].

The objectives of this study were to:

1) build a weed flamer with torches that can rotate in the vertical axis to flame in different angles for in-row and surface flaming,
2) apply flames at different ground speeds and different heights to capture the thermal images of heat distribution, and
3) determine whether a low pressure gas nozzle can be used to provide heat surface coverage.

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II. Materials And Methods

A. Materials

A two meter weed flamer with 8 torches was developed for weed control research (Fig. 1). The system consists of a 580 L gas tank (with pressure release valve, fuel level gage, and propane charging inlet), a pressure regulator, a back pressure valve, gas distributer, gas hoses, and torches. The system was integrated with a field cultivator, but the cultivator has no implications for this paper.

Fig. 1. The weed flamer developed for thermal flaming studies

The flaming angle of the torches can be changed easily (Fig. 2) with the current set up, they can be moved up and down in the vertical direction (Fig. 3), or can be directed perpendicular to the moving direction of the tractor (Fig. 3).

Fig. 2. Flame angle adjustment on the weed flamer

Fig. 3. The height adjustments and rotation of the torches to the sides

A small gas nozzle with a 1.5 mm nozzle diameter was used for burning the gas for flaming. For determining the pressure-flow rate relation of the nozzle, a digital scale with 30 kg capacity with 1 g resolution was used. For these tests 12 kg LPG tank was used. The selection of 1.5 mm nozzle was based on a previous study conducted with three different nozzles and four different torches [12]. The pressure-flow rate characteristic of the nozzle is given in Fig. 4, showing a linear relationship between the pressure and flow rate.

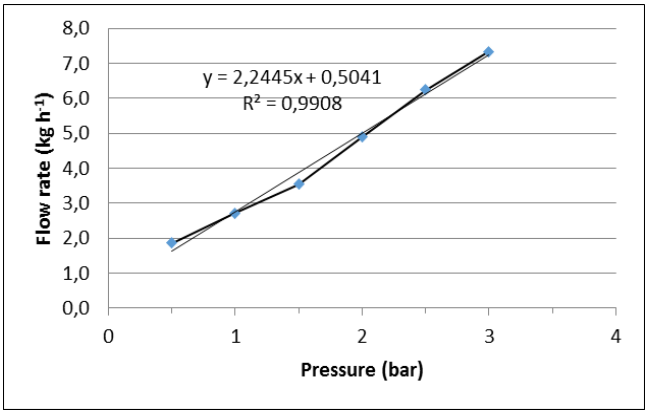


Fig. 4. Pressure-flow rate relationship of the gas nozzle used to develop the flame torch [12]

Based on the pressure selection (0.2 MPa), the ground speed requirements will vary from 1.6 to 8.1 km h^{-1} to apply doses from 15 to 75 kg ha^{-1} (Fig. 5). Lower pressure values of 0.15 and 0.1 MPa may also be applied to obtain the same doses. However, the length of the flame reduces with the reduction in the pressure, requiring less flaming heights. This in turn will reduce the area covered by the flame since the width of flame on the ground reduces when the torch approaches the ground. Therefore, the best pressure setting was selected to be 0.2 MPa. The ground speed needs to be greater than 10 km h^{-1} when the pressure is greater than 0.2 MPa. This condition is not favourable since the heat effect will be very short over the weeds in the field conditions. Therefore selection of an applicable pressure was based on a pressure setting that does not require high speeds, and 0.2 MPa was selected to be a good pressure value.

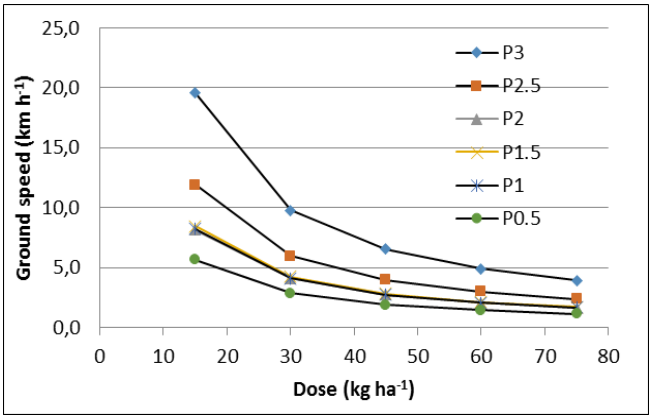


Fig. 5. The calculated ground speeds based on different pressure settings and applied doses [12]

A thermal camera (Testo T850) capable of measuring temperatures up to 1200 ºC was used to obtain the thermal images of the flames behind the tractor.

B. Methods

Calibration of the nozzle consisted of two stages. First, the pressure-flow rate characteristic of the nozzle was determined by measuring the mass flow rate of the nozzle at different pressures (0.05, 0.1, 0.15, 0.20, 0.25 MPa). For this purpose the gas burning system was connected to the LGP tank with 12 kg capacity. The gas was burned for 1 minute and the weight of the tank before and after the test was measured to find the amount of gas burned during each test.

The tests were replicated four times at each pressure setting and the average flow rate of the nozzle was determined. The flow rate – pressure curve of the nozzle was graphed. In the second step, the ground speed of the tractor was calculated based on the doses (0-75 kg ha^{-1}) and the pressures tested. Finally, a pressure setting was chosen that could be used with appropriate ground speeds. Flame width at 0.2 MPa was found to be 0.25 m.

To use the right ground speeds during field testing, before the field experiments, the gear and engine speeds were selected for each dose to be applied. Forward speed of the tractor was determined by measuring the time needed to travel a known distance (20 m) on a flat soil surface. These tests were done with two or three replications until the desired speed was obtained, and the gear and engine rotational speeds were determined for each ground speed needed for the necessary doses.

For field testing, the desired pressure was set using the pressure regulator, the torch height was adjusted, and the ground speed were selected. The thermal camera was located on the ground at the same height as the torch about 0.5 m far from the rear tire of the tractor. Thermal images were obtained as the flamer passed by the thermal camera.

Among the 5 doses selected, thermal images relating the smallest (15 kg ha^{-1}) and the largest (75 kg ha^{-1}) doses corresponding to the slowest and fastest ground speeds were reported for discussion.

III. Results and Discussion

Thermal images during flaming under different working conditions are given in Fig. 6. The pictures were obtained as the tractor moved to the left while the flame is targeted to the ground behind the tractor with 30° angle.

At the lowest ground speed (1.6 km h^{-1}) changing the torch height from 200 mm (Fig. 6a) to 250 mm (Fig. 6b) with reference to the ground showed little effect as the length of the heat distributed over the ground was similar in both cases. However, the thickness of the heated zone was better scattered in Fig. 6a. Although heat distribution patterns looked similar, applying heat from a higher position (Fig. 6b) increased the heterogeneity in the heat distribution.

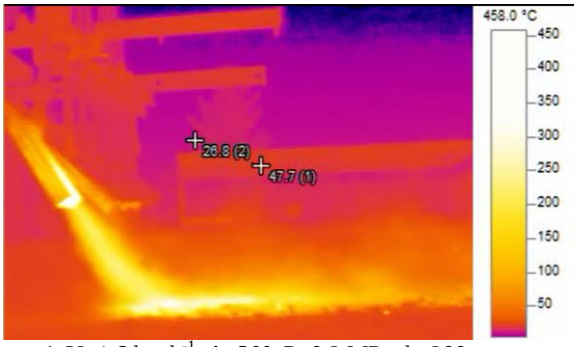
In Fig. 6c and 6d, the angle and pressure settings were the same as Fig. 6a and 6b, respectively. However, the tractor moved at the highest ground speed, giving the smallest dose of 15 kg ha^{-1} in the case of Figs. 6c and 6d. The effect of forward speed of the tractor was apparent with little heat effect on the ground at the highest ground speed. At 200 mm height, the flame seemed to reach the ground. The flame seemed to be gently sweeping the ground, leaving a thin heat trace, depicted by the dispersed cloudlike heat wave over the surface. When the torch height was increased to 250 mm (Fig. 6d), the flame and hence the heat barely reached the ground, suggesting very small heat effect on the ground.

At slow ground speed, the flame length was about the same both at 200 mm and 250 mm heights. However, at the high speed, there was a notable difference in the flame length. In terms of flaming height, 250 mm showed almost no effect on the ground while 200 mm height provided some residual heat traces. When the low and high ground speed tests were compared, there was significant difference in the heat reaching and spreading on the ground in favour of slow ground speed. The flame length during the slow ground speed flaming, the flame length was roughly 0.45-0.55 m while it was less than 0.15 m in the worst case (Fig. 6d).

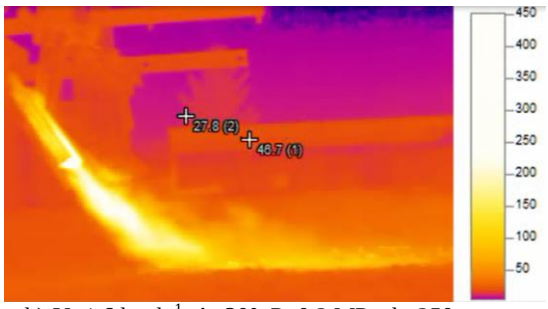
The effect of increased pressure was also tested in addition to the tests conducted in this study. However, the ground speed was not re-calculated to obtain the same doses. Rather, the effect of increased pressure (0.25 MPa) was sought with all other parameters were the same as previous tests. The resulting thermal images are given in Fig. 7. The difference between 0.2 to 0.25 MPa was not high, but the effect of increasing the pressure was notable, particularly at high speed (8.1 km h^{-1}) flaming. In Fig. 6d, the flame had no effect on the ground whereas in Fig. 7d, the flame hit the ground and left a heat wave over the surface for the longest distance among all cases. The length of the heat trace should might have been affected by the wind effect of the tractor, which was much higher compared to the slow ground speed (Fig. 7a-b).

Based on observations made on thermal camera images, it could be argued that 0.2 MPa pressure can be used at low ground speeds, corresponding to relatively high doses, particularly with torch height at 200 mm. If the flame is applied to the target from a higher distance, the effect of the flame will be diminished. At high ground speeds, 0.2 MPa may have little effect on weeds that have gained heat tolerance. Therefore, the calibration should not rely only on the constant gas pressure with varying ground speeds. Rather, the pressure setting should be changed to apply different gas doses at a constant ground speed. A combination of different settings for both the ground speed and pressure may also be applicable.

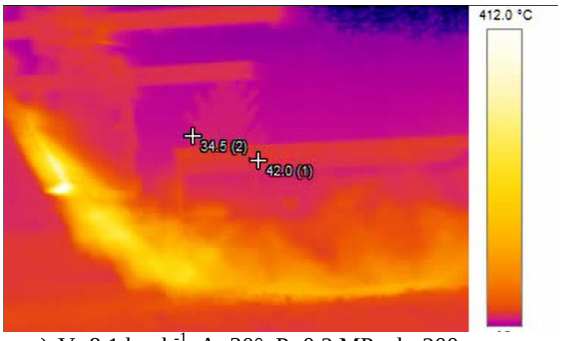
The gas nozzle with 1.5 mm diameter could be used at 0.25 MPa, in which case the length of the flame can be increased in all cases compared to 0.20 MPa. This is more favourable for weed species that are more tolerant to the heat or that are not in the early growth stages.



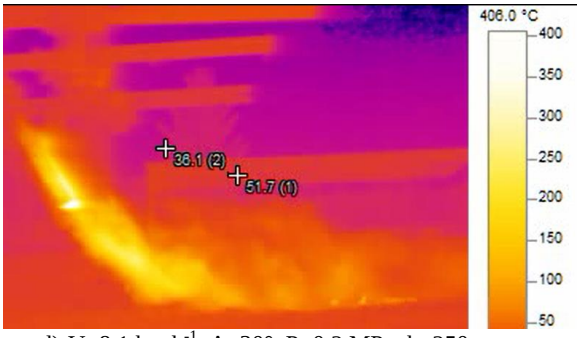
a) V=1.6 km h^{-1}, A=30°, P=0.2 MPa, h=200 mm



b) V=1.6 km h^{-1}, A=30°, P=0.2 MPa, h=250 mm

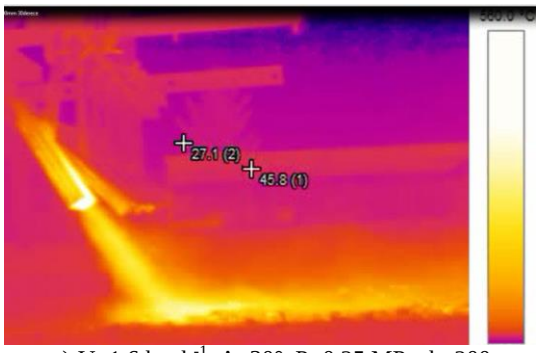


c) V=8.1 km h^{-1}, A=30°, P=0.2 MPa, h=200 mm

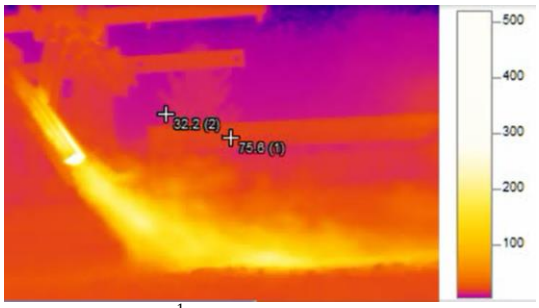


d) V=8.1 km h^{-1}, A=30°, P=0.2 MPa, h=250 mm

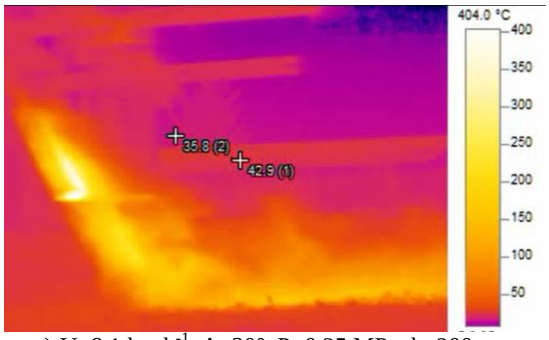
Fig. 6. Thermal images of the flame at a pressure of 0.2 MPa (V: Ground Speed, A: Flaming angle, P: Gas pressure, h=Flame height from the ground)



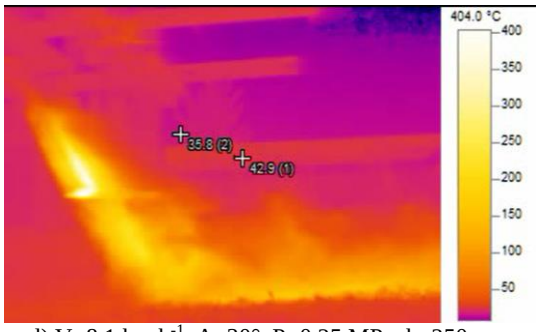
a) V=1.6 km h^{-1}, A=30°, P=0.25 MPa, h=200 mm



b) V=1.6 km h^{-1}, A=30°, P=0.25 MPa, h=250 mm



c) V=8.1 km h^{-1}, A=30°, P=0.25 MPa, h=200 mm



d) V=8.1 km h^{-1}, A=30°, P=0.25 MPa, h=250 mm

Fig. 7. Thermal images of the flame at a pressure of 0.25 MPa (V: Ground Speed, A: Flaming angle, P: Gas pressure, h=Flame height from the ground)

It can be proposed that, the effect of speed on heat distribution should be determined along with other parameters used for calibration such as flamer width, ground speed, and flow rate and pressure characteristics. A flamer can be calibrated to apply a given propane or LPG dose, but the flame distribution over the soil surface may have a defining effect on

the success of flaming application. Therefore accurate calibration procedure of the flamer is not limited to be able to apply a given dose, but should include good temperature distribution over the soil. Further research is needed for the nozzle selected in this study, which should focus on the determination of two and three dimensional heat distributions, through both stationary and mobile testing, to better understand the effect of the parameters used for calibration.

IV. Conclusion

A broadcast flaming machine with 2 meter swath width was developed for weed control, which was mounted on the hitch of an agricultural tractor. Pressure-flow rate characteristics of the 1.5 mm nozzle was determined. Depending on the flame width and gas doses to be applied (0-75 kg ha^{-1}), required ground speed of the tractor was calculated. Thermal images of the flames were obtained at the minimum (1.6 km h^{-1}) and maximum (8.1 km h^{-1}) speeds, corresponding to the highest dose (75 kg ha^{-1}) and lowest dose (15 kg ha^{-1}) selected for field testing. Based on the visual observations of the thermal maps, it was concluded that the nozzle selected for relatively low pressure (0.2 MPa) application could not be efficiently used at high ground speeds, especially when the flame was applied from a height of 250 mm. The pressure setting at 0.2 MPa may only be used if the torch height is 200 mm. The pressure should be increased to 0.25 MPa since the temperature distribution over the surface was clearly improved in this case. Temperature distributions should be determined in 3D and from the rear of the tractor to get more information about the behavior of the flame over the surface.

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