



Original Research

Construction and evaluation of flame weeding to remove weed in corn and sugar beet rows

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ABSTRACT

Weed increase reduces crop yields, while chemicals applied to control weed have adverse environmental impacts. Thermal control has a less negative effect on the environment and health of consumers compared to chemical methods. After construction, the flame weeding efficiency of this method for eliminating near-row weed at three speeds of drive and three different amounts of liquid gas consumption was evaluated. The flame weeding manufactured and connected to the back of an offset tractor and navigation system. The flame weeding had a sidewall that prevented the flame from directly touching crop plants inside the row. Flame weeding were performed based on split-plots and on randomized complete block design with two factors of movement speed at three levels of low (3 km/h), medium (4 km/h) and high (5 km/h) and liquid gas consumption does at three levels of low (3 km/h), medium (5 km/h) and high (7 km/h). The results in both sugar beet and corn showed the interactive effects of two speed and amount consumption factors on each other. Weed control rates had varied considerably with flame treatment at different speeds and doses of liquid gas. With the increasing speed and decreasing liquid gas, the average weed control ratio decreased from 0.86 to 0.1. needle leaf weed control ratio in all cases is less than broadleaf weed. As the advance rate and the amount of liquid gas consumed decreases, the proportion of weed control declines substantially, and vice versa. This trend showed an inverse correlation between speed and liquid gas consumption factors.

Introduction

During the post-World War II years, most of the researches on weed control have focused on the development of a technology for weed management rather than eradication. This has been the result of growing our knowledge regarding complex ecosystems and accepting pests and weed as a part of agricultural systems. Therefore, experts attempt to apply this knowledge to develop weed management strategies while using into consideration the economic, ecological and social factors (Upadhyaya and Blackshaw, 2007). Outlined five methods of crop protection including chemical control, physical control,

biological control (resistant crops, genetically modified crops), biological toxins (use of some plant, virus, and bacterial products) and human factors. Each method has its advantages and disadvantages, for example, chemical control entails, legal pressures and food safety standards which restrict the use of this method (Vincent et al. 2001). Nowadays, with increasing concern about environmental safety and human health, the application of flame weeding has become popular among farmers (Laguë et al. 2001; Leroux et al. 2001). Flame weeding is an effective mechanism in weed control with more flexibility under different environmental conditions, especially in wet and sandy soils (Stepanovic, 2013). This method used in part of western Europe in some areas where weed control is the only system (Rasmussen and Ascard, 1995). Similarly, in the United States, flame weeding was used for a variety of crops such as cotton, corn, grapes (Laguë et al. 2001). Many efforts have made to construct and develop flame weeding. Different structures and systems are used for construction, depending on the area and product conditions. Various factors influence the efficiency of flame weeding including, the design of the flame weeding, the fuel consumption of the system, growth stages of the crop and environmental conditions. For example, Neilson (2012) proposed a combination of a flame weeding and a cultivator. The overlay plates designed for using a strip flame weeding technique and two burners were positioned at 30 ° from each other, backward on either side of the row of corn. The system successfully controlled 90 percent of the weed in the field with a consumption of 39 kg propane per acre. Ulloa et al. (2010) tested the flame tolerance of weed in different growth stages. They reported that the tolerance of both broadleaf and needle leaf to flame propagation increased with the growing plant. Comparing foxtail plants with five plant species, they suggested that the use of propane flame at the appropriate dose could control 99 percent of needle leaf and 90 percent broadleaf plant. Stepanovic (2013) compared the effects of flame and cultivator on the corn crop for weed management. He reported that corn had a high tolerance to all flame treatments. He suggested applying a strip flame followed by a cultivator performed twice for 90 percent of weed control. These findings indicated that flame weeding and cultivators are potentially useful in corn production systems.

In this study, we aimed to develop a flaming weed at the University of Tabriz, which is suitable for needle leaf and broadleaf weed on corn and sugar beet fields. The weed in the field -tested included both broadleaf and needle leaf. The performance and efficiency of the flaming weed in the field are tested and reported.

Material and Methods

Test field

The study conducted from March 2014 to February 2015 at the University of Tabriz. The field station located at the latitude of 46.433 and longitude 38.018 at an altitude of 1663 meters above sea level. For the field tests, three rows of sugar beet and three rows of corn crops cultivated in a

30×10 m plot of the farm. The space between the rows for sugar beet and corn was 75 cm, the distance between plants in corn was 5 to 7 cm and the distance between plants in sugar beet was 3 to 4 cm. During growing, fertilizers and toxins were not given to crops and irrigated twice a week. The flaming weed applied when the weed was at 3 to 4 leaf stages, as that is the critical time for flame weeding (Knezevic et al. 2012). The weed control method was applied to evaluate the number of weed in the treated area (Vanhala et al. 2004).

Construction

The flaming weed manufactured and connected to the back of an offset tractor and navigation system described and was made by Behfar (2014). The product consists of three main parts including the frame, the flaming and the navigation system. The rectangular frame was attached to the tractor three-point hitch. Underneath the mainframe was a sliding plate that was driven by components of the navigation system and the weeding part is attached to it using toggle joints. The weeding part consists of two torches with 50 cm hoods which rest on either side of the crop row and are driven by the navigation system. The navigation system detects the crop rows and directs the weeding part where the crop row falls between two cover plates and treats weed (Figure 1).

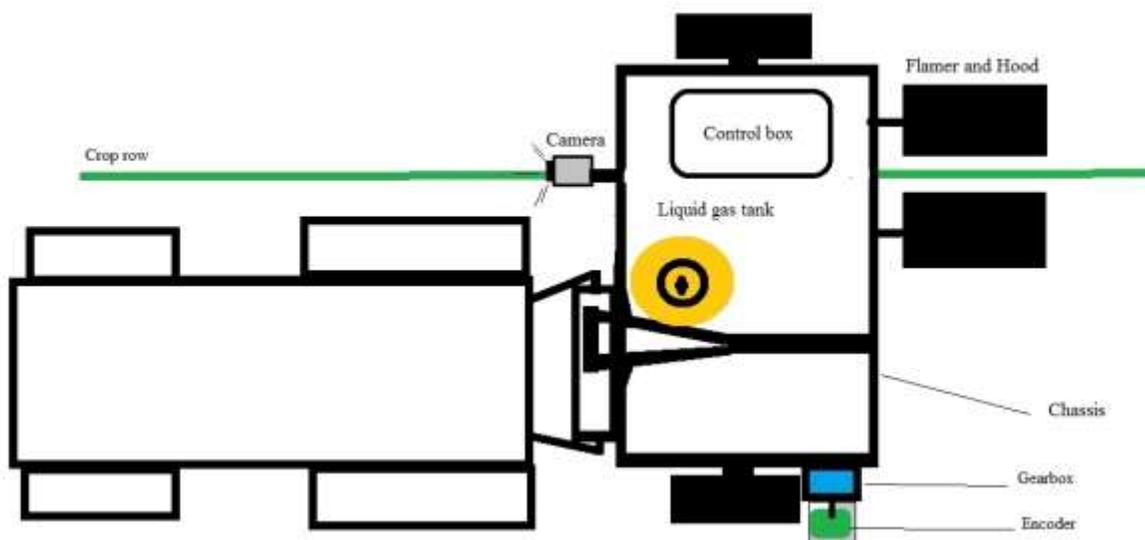


Figure 1. Schematic shape of the machine.

Once the crop row detected by the system, the operating navigation system puts the weed in a suitable position to apply the treatments to the rows. An off-set tractor made by Biosystem Engineering Sample Workshop at Tabriz University used. With few changes to the chassis of the tractor, the flame weeding system installed on the tractor. The machine was off-set made and was able to treat the side rows of crops at a range of 50 to 80 cm. The flame weeding has a 25 cm

moving wheel and is 35 cm above the ground. In the lower part, a 5 mm thick steel plate (slider plate) is placed with dimensions of 50×40 mm. The slider plate was attached to the rails at the bottom of the machine with 16 screws No. 8. The rail embedded in the frame consists of two circular axes 25 mm in diameter and 120 cm long which are attached to the main chassis with four UCP 205 bearings. On each axle, two 25mm in-line ball bushing bearings allow the sliding plate to move transversely on the rails. The power for moving the sliding plate provided by a DC electric motor. The bolt system used for the convert rotary motion of the electric motor and the linear motion also the pivot axis rotates, the nut moved along the bolt axis and the plate which welded to the nut movements. The bolt number is 18 and the screw length is 100 cm. The base of the camera is also welded to the slider plate and moves along with that. After detecting the camera's deflection from the crop row by the navigation system, an electric motor turns on and the gearbox while reducing the speed turns the bolt. As a result, the plate and camera movement as well so that the camera can follow the row and guide the weeding agent in the middle of the row (Figure 2). The burners are equipped with 50 mm diameter covering plates and connected to the regulator with a gas hose and placed to the inside of the covering plates. The burners positioned backward aligned with the movement direction with a 30-degree angle. Flaming placed on a height of 10 cm above the ground and centered on the covering plates.

Cover plates

The covering plate has a sidewall that prevented the flame from directly touching the crop inside the row. The plates were made into hollow rectangular cubes that were 50 cm long, 20 cm wide and 15 cm high, with a spacing of 6 cm relative to the row. Each of the plates is connected by a 20-mm arm to two axes with a diameter of 20 mm. The axle can be connected to the slider by means of two UCP 204 bearings and you distribute the radial rotation to your transparency which you can power through the overlapping plates. Part of the cover plates, which contacted the surface, were bent 20 mm in width and about 90 degrees bent along the cover plates to play the role of the shoe, preventing the plates from plunging into the soil.

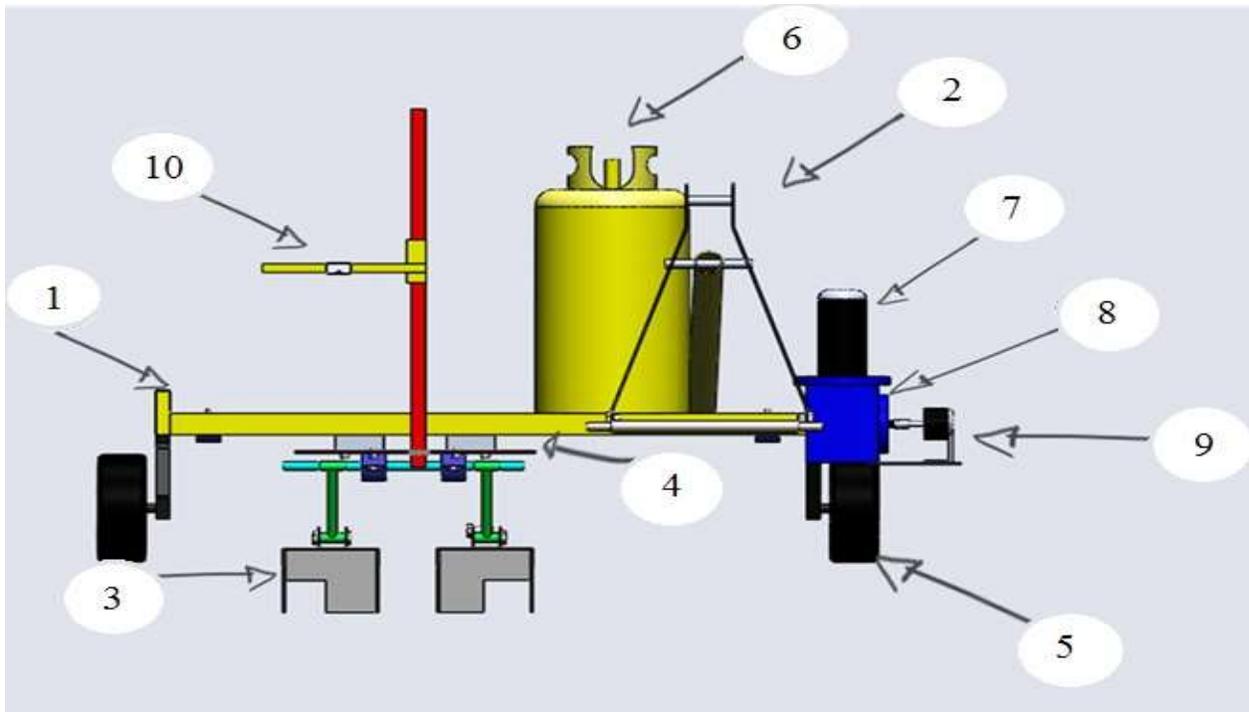


Figure 2. Shape of the machine in solid work.

1- Main frame measuring 132 x 67 cm, 2- Three-point junction, 3- burners and covering plates, 4- Slider, 5- Wheels, 6- Liquid gas tank, 7- DC motor, 8- gear reducer, 9- Encoder, 10- Camera.

Performance evaluation

The tractor used in this study was the Goldoni 930 tractor manufactured by the Urmia Tractor Factory. Before the flame treatments, tractor speed tests were conducted in the field. Flame treatments were performed based on split-plots and on completely random blocks with two factors of movement speed at three levels of low (3 km/h), medium (4 km/h) and high (5 km/h) and liquid gas consumption does at three levels of low (3 km/h), medium (5 km/h) and high (7 km/h). The tractor was controlled by a driver and a user controlled the liquid gas valve (Table 1). Weeds were measured before and 10 days after treatments. Also, field tests with a wooden frame (100 × 50 cm) were repeated five times from July to October 2015.

Statistical analysis of test results

The data obtained collected as the ratio of weed removed to total in each plot. The data for both corn and sugar beet crops were analyzed separately with MSTATC software. The differences between treatments were compared using Duncan's multiple range test ($\alpha = 5\%$). As shown in Table 1, as the tractor speed up, retention time and liquid gas consumption per hectare decrease. The retention time to flame is calculated using the following equation:

$$t = \frac{1}{V} \times d$$

where t is the time in seconds, v is the speed in meters per second, and d is the length of the covering plates.

Table 1. Treatments and related specifications.

Treatment	Speed km/h	Speed m/s	Liquid gas consumption(kg/hr.)	Liquid gas consumption(kg/ha)	Retention time
a ₁ b ₁	3	0.84	3	13.3	0.60
a ₁ b ₂	3	0.84	5	22.2	0.60
a ₁ b ₃	3	0.84	7	31.1	0.60
a ₂ b ₁	4	1.11	3	10.0	0.45
a ₂ b ₂	4	1.11	5	16.6	0.45
a ₂ b ₃	4	1.11	7	23.3	0.45

Results and Discussion

Sugar beet

The highest densities of the weed were related to the three types of broadleaf weed, including *Portulaca oleracea L*, *Amaranthus*, *Convolvulus arvensis* and two needle leaf weed, including *Sonchus arvensis* and *Alopecurus*. Weed control rates had varied considerably with flame treatment at different speeds and doses of liquid gas. With the increasing speed and decreasing liquid gas, the average weed control ratio decreased from 0.86 to 0.1. needle leaf weed control ratio in all cases is less than broadleaf weed (Table 2).

Table 2. Weed control ratio in cultivation of sugar beet.

Treatment	Needle leaf	Broad leaf	Total
a ₁ b ₁	39.0	46.0	43.0
a ₁ b ₂	66.0	71.0	68.0
a ₁ b ₃	83.0	89.0	86.0
a ₂ b ₁	27.0	31.0	29.0
a ₂ b ₂	38.0	43.0	41.0
a ₂ b ₃	61.0	68.0	64.0
a ₃ b ₁	08.0	13.0	11.0
a ₃ b ₂	19.0	24.0	22.0
a ₃ b ₃	27.0	33.0	30.0

Although with increasing speed and decreasing the amount of liquid gas, heat transfer into the rows decreased and fewer bushes were removed, the proportion of sugar beet bush removal was not significantly different. However, other factors may also be involved in the number of bushes removed, such as late germination of the plant and, consequently, the presence of weak plants in the row, and The flame weeding deflection that causes heat to reach close to the crop. There is also a possibility of error due to the low number of plants in the row (Figure 3 and Table 4). The effect of speed factor, the amount of liquid gas consumed and their interaction were significant at the ($\alpha=1\%$). Among the average treatments, a₁b₃ had the best yield. There was no significant difference

between a1b2, a2b3, a2b2, a1b3, a3b3 treatments, a3b2 treatment was at the lower level and a2b1 and a3b1 treatments had the lowest yield. This trend was almost similar in all three tests of mean comparison (Figure 4). In the data of the removed sugar beet bushes, the effect of speed and liquid gas was significant ($\alpha=5\%$). In the data of the removed sugar beet bushes, the effect of speed and liquid gas was significant ($\alpha=5\%$). Interaction between these two factors was not significant (Table 5). In mean comparisons using Duncan, multiple range test ($\alpha = 5 \%$) shown that the first level of the speed factor (3 km / h) was significantly different and more effective than the other two levels. The other two speed levels (4 and 5 km / h) did not differ significantly ($\alpha = 5 \%$) (Figure 5). There was no significant difference in the amount of liquid gas with any of the other levels (Figure 6).

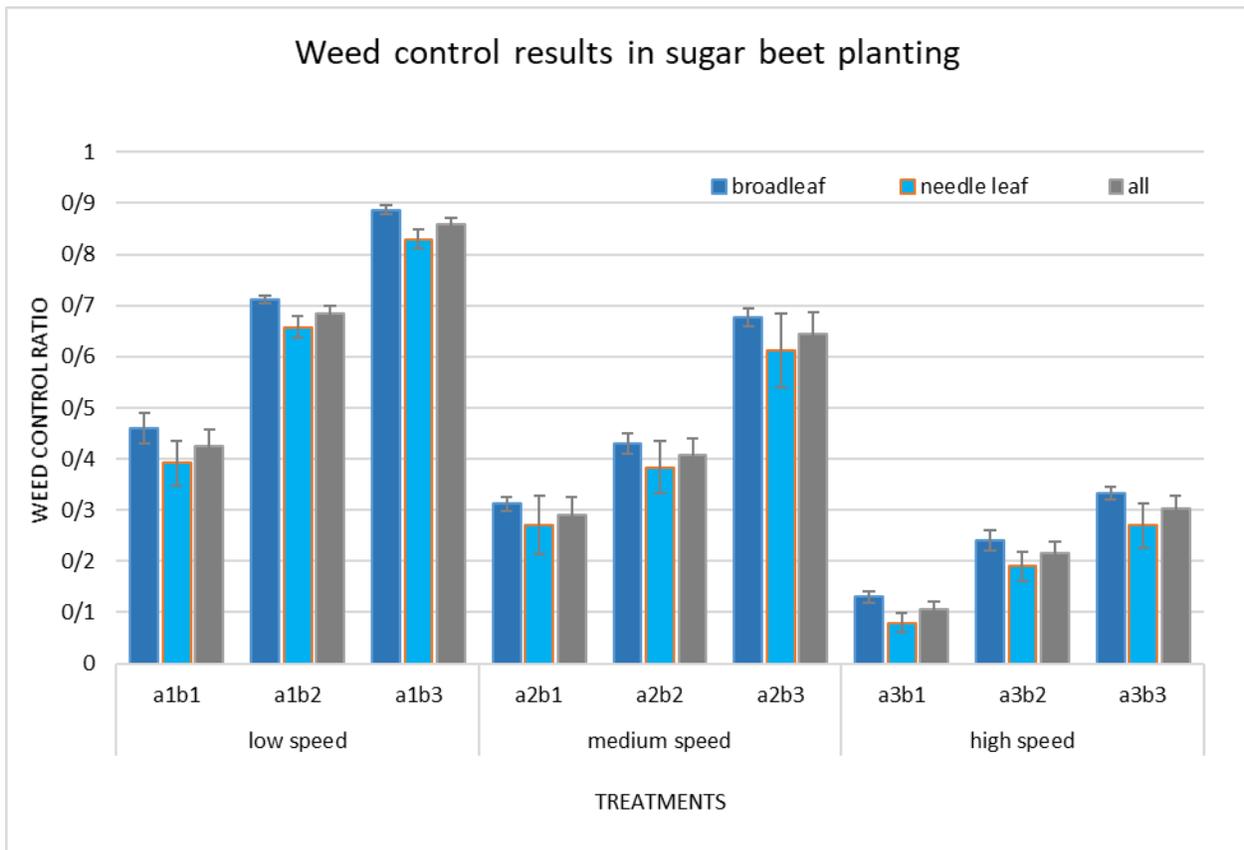


Figure 3. Weed control results in sugar beet planting.

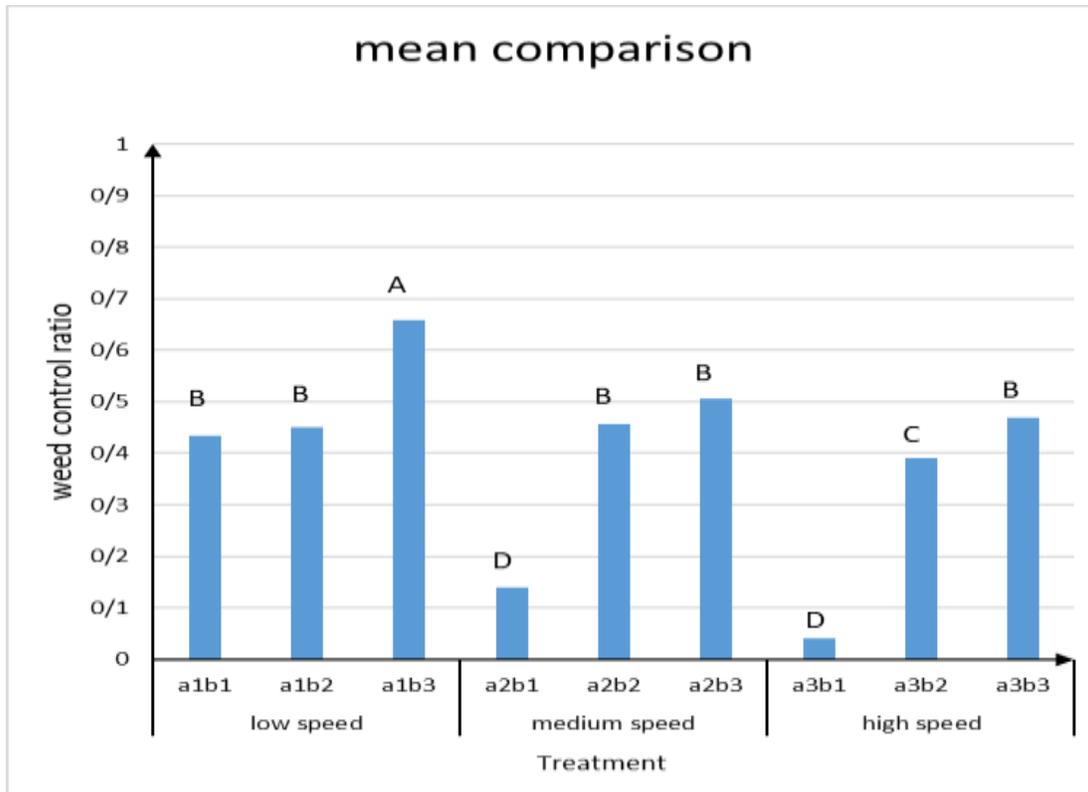


Figure 4. Weed control ratio in sugar beet.

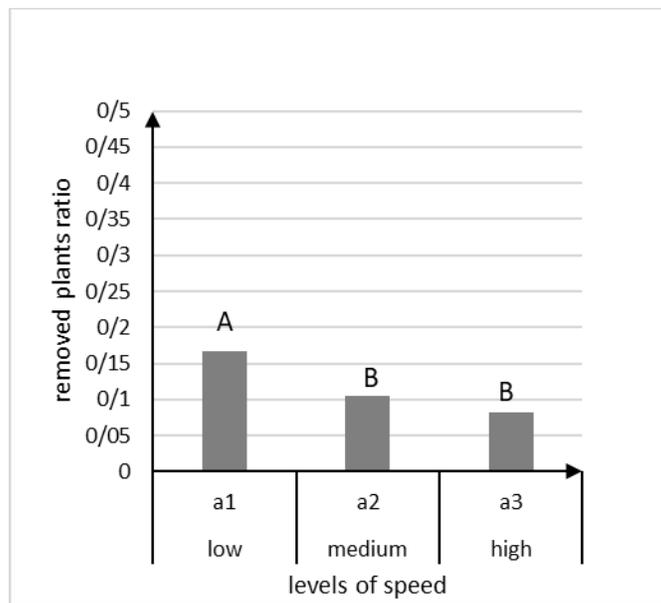


Figure 5. Effect of speed levels on removal of sugar beet plants.

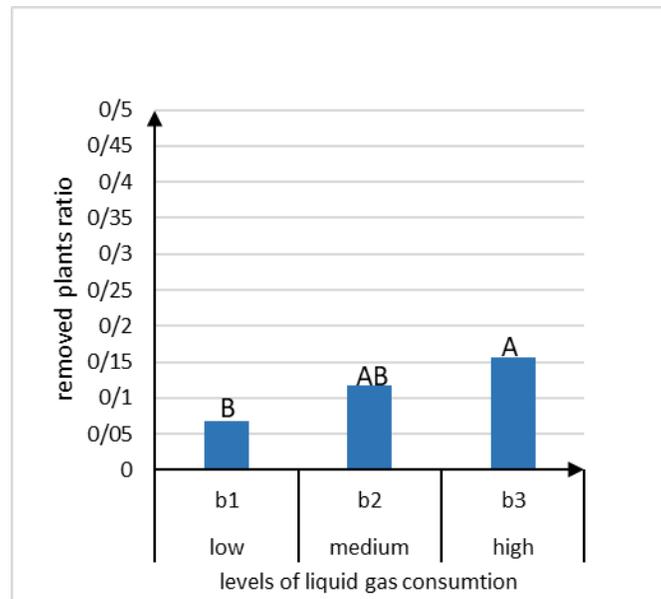


Figure 6. Effect of speed levels on removal of corn plants.

Corn

Results obtained of weed removal ratio in corn were due to the same conditions and weed was similar to results obtained in the sugar beet (Table 3). Regarding the fitting curves of the mean weed control, the weed control ratio has a directly related to the increase in liquid gas and inversely related to the increase in speed. According to the data obtained from the separate counts of broadleaf and needle leaf weed, the results show that the resistance of needle leaf is higher than broadleaf and the control distance increased with an increase in speed and decrease in liquid gas (Figure 7). After the corn leaves collided to the covering plates some leaf wilting was observed which after 10 days improved and the plant continued to grow (Figure 8). The table of data variance analysis obtained from the weed control ratio in corn shows that the results were approximately similar to the results obtained in sugar beet. The effects of speed factor, liquid gas and interaction were significant ($\alpha = 1\%$) (Table 6). Compared to averages, a1b3 and a1b2 has the best performance, a3b1 treatments have the worst performance and a2b3, a2b2, a1b3, and a3b3 treatments were not significantly different (Figure 8). The results of the analysis obtained in sugar beet and corn indicated the interaction effects of speed and liquid gas factors on each other. With increasing speed and decreasing liquid gas, the proportion of weed control substantially reduced.

The procedure showed the inverse relationship between speed and liquid gas factors. With increasing speed, retention time decreased that with increasing flame intensity should be compensated. Wszelaki et al. (2006) investigated the effect of flaming weed on weed removal in tomato and cabbage plants. He stated that low flaming in both plants increased crop yield

compared to untreated control. In this paper, among the treatments applied to two crop rows, a1b3 treatments (3 km/h speed and 7 kg/h liquid gas) and a1b2 and a2b3 treatments (3 km/h speed and 5 kg/h liquid gas, 4 km/h speed and 7 kg/h liquid gas) provided acceptable control. As a result, a2b3 treatment has more economic advantages than a1b2 treatment. With examining the amount of damage caused by flame treatments to the treated crops, it can be concluded that the flame treatments did not have much effect on the removal of corn, but in the case of sugar beet, the flame treatments resulted in the removal of the plants in the crops that the most its proportion belongs to the a1b3 treatment.

Table 3. Weed control ratio in cultivation of corn.

Treatment	Needle leaf	Broad leaf	Total
a ₁ b ₁	0.43	0.46	0.45
a ₁ b ₂	0.57	0.67	0.62
a ₁ b ₃	0.83	0.85	0.84
a ₂ b ₁	0.27	0.33	0.30
a ₂ b ₂	0.44	0.47	0.45
a ₂ b ₃	0.54	0.62	0.58
a ₃ b ₁	0.04	0.08	0.06
a ₃ b ₂	0.16	0.20	0.18
a ₃ b ₃	0.26	0.34	0.30

Table 4. Analysis of variance of weed removal data in the vicinity of sugar beet rows

Sources of changes	Degree Of Freedom	Mean square		
		Broad leaf	Needle leaf	Broad leaf And Needle leaf
block	2	0.003*	0.037 ^{ns}	0.011*
Speed	2	0.396**	0.377**	0.389**
Type i error	4	0.01	0.003	0.001
Liquid gas consumption	2	0.303**	0.207**	0.281**
Speed* Liquid gas consumption	4	0.009**	0.008**	0.014**
Type ii error	12	0.001	0.001	0.001
Coefficient of variation		81.6%	47.8%	40.5%

ns: not significant, * significant at the 5% level ** significant at the 1% level .

Table 5. analysis of variance of data on the removed sugar beet bushes.

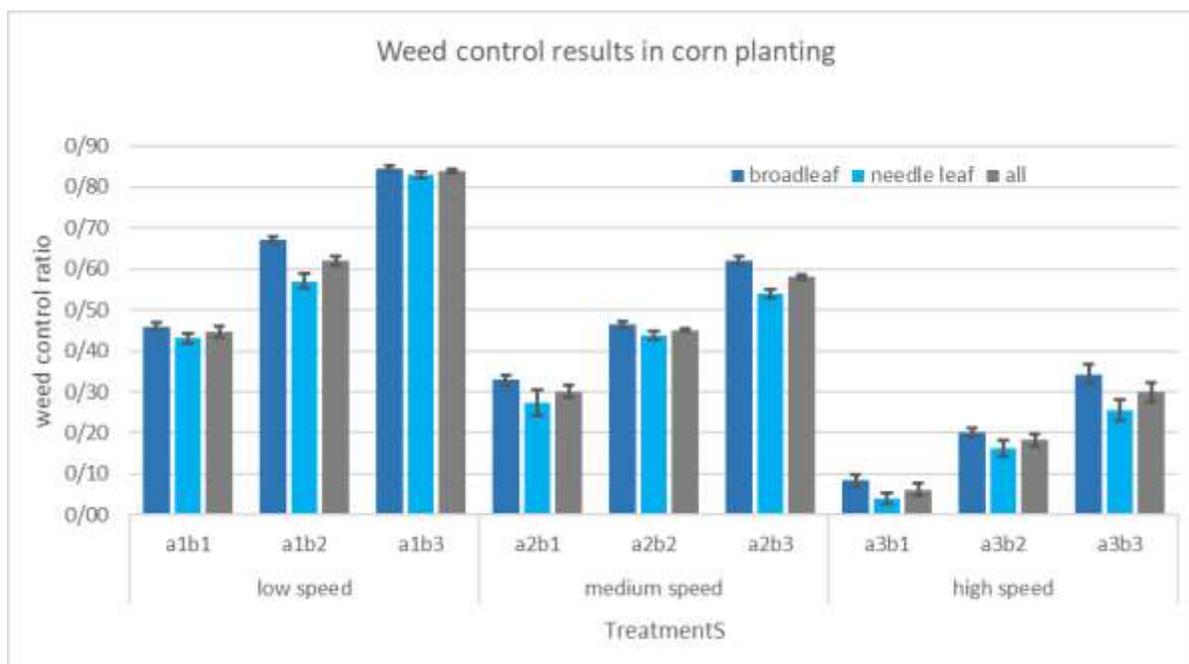
Sources of changes	Mean square	
	Degree Of Freedom	Damage to sugar beet bushes
Block	2	0.01 ^{ns}
Speed	2	0.018*
Type i error	4	0.002
Liquid gas consumption	2	0.022*
Speed* Liquid gas consumption	4	0.001 ^{ns}
Type ii error		0.003
Coefficient of variation	12	46.6%

ns: not significant, * significant at the 5% level ** significant at the 1% level .

Table 6. Analysis of variance of weed removal data in the vicinity of corn rows.

Sources of changes	Degree Of Freedom	Mean square		
		Broad leaf	Needle leaf	Broad leaf And Needle leaf
Block	2	0.006	0.037 ^{ns}	0.011*
Speed	2	0.388**	0.377**	0.389**
Type i error	4	0.001	0.003	0.001
Liquid gas consumption	2	0.325**	0.207**	0.281**
Speed* Liquid gas consumption	4	0.003**	0.008**	0.014**
Type ii error	12	0.001	0.001	0.001
Coefficient of variation		92.4 %	47.8 %	40.5 %

ns: not significant, * significant at the 5% level ** significant at the 1% level .

**Figure 7.** Weed control results in corn.

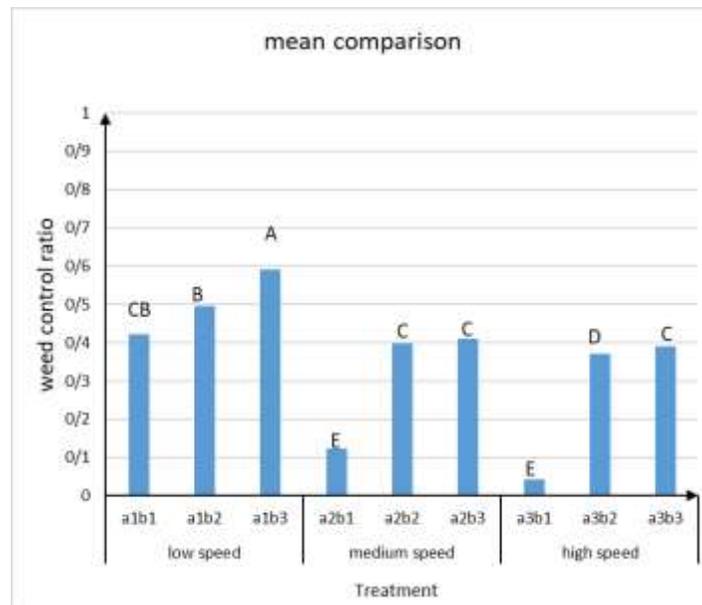


Figure 8. Weed control ratio in corn.

When weed is in the 1-4 leaf stage, the LPG needed to reduce weeds by 95 percent is about 40 kg/ha. When weed is in 4-12 leaf stage, 2-4 times liquid gas is needed compared 1-4 leaf stage. In this study, the removed shrubs were mostly young germinated plants that did not reach the appropriate growth stage for high temperatures. To prevent poor performance, it is suggested that flame weeding in sugar beet plant be conducted before thinning. In an experiment, Bruening (2009) compared an uncover flaming and a cover flaming. The length of the flaming cover plates used in the experiment was 1.2 m. The results showed that the same level of weed control could be achieved with flame weeding with cover, with an average of 50 percent less propane consumption than uncovered flame. While keeping the flames and heat on the ground away from the tractor user, the applied covered plates increase the safety of the flaming. In this article, when using cover plates, which turns out that in case of deflecting from the route, it not only exposes the crops to direct flame but also damages them mechanically. Mechanical and thermal damage to the crops occurs when the weed deflection from the original path exceeds the specified value (6 cm). Deflections between 2 and 5 cm were likely to cause thermal damage, and deflections less than 2 cm might have been caused by the error of the navigation system in detecting the crops row. Overall, considering the amount of weed control in flame treatments and also the deflections in the weed movement path, the a1b3 treatment (3 km/h and 7 kg/h of liquid gas consumption) can be considered as the most suitable treatment among the treatments, as it had the least deflection from the path of movement and the highest proportion of weed control. Of course, economic considerations must be taken into account when choosing the appropriate treatments for weeding. It should be studied to

find which of the following treatments can maximize profitability by considering economic factors such as fuel prices, loss of performance due to over-control or low control, and operating costs.

Conclusion

In this paper, the effect of flame weeding made on the grasses of corn and sugar beet were investigated. The results in both sugar beet and corn crops show the interaction effects of two factors of speed and amount of liquid gas consumption on each other. Increasing the rate of advance in flame weeding treatments reduces retention time of the target plants, which in turn reduces the heat transfer rate to these plants, which should be compensated by increasing flame intensity or the same amount of liquid gas consumption. Cover plates play an important role in reducing flame damage to the original product by preventing direct flame impacts on products grown on the rows but may cause mechanical damage to the products by straying from their original course. Using the navigation system at the right speed is very useful to prevent the device from straying from the track.

Conflicts of Interest

Authors confirm that there is no conflict of interest to disclose.

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