Post-emergence thermal weeding in onions (Allium cepa)

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Abstract

Field trials were conducted on commercial organic farms over three years to study the effects of post-emergence thermal weeding in onions (*Allium cepa*). The results demonstrated the potential of both flame and steam weeding for post-emergence use in onions provided the operation was timed carefully. Early post-emergence thermal weeding is more effective because weeds are smaller, but onions should have at least two leaves to withstand the heat. Following a pre-emergence thermal weeding, two post-emergence passes of either a flame or steam weeder at the 3-leaf and 5-leaf growth stage of onions gave economical weed control. This strategy gave a significant yield improvement over the control. In experiments where hand weeding was used to remove mid-season weeds, yields were similar, but labour required for hand weeding after thermal weeding, was reduced by up to 80%. Onion bulb size was also significantly greater in plots that had two post-emergence passes of thermal weeding provided one was at the 3-leaf onion growth stage. None of the thermal treatments used increased the incidence of neck rot in onions. The 3-leaf growth stage appears to be a key timing for effective weed control in onions.

Additional keywords: integrated weed management, non-chemical weed control, organic weed control, flame weeding, steam weeding, weed control cost

Introduction

Onions (*Allium cepa* L.) are an important cash crop for New Zealand domestic and export markets and rank number one among vegetable crops in terms of export value. In 2007 New Zealand exported more than 186,000 t of onions, with a value about NZ $121 million (Anonymous, 2010).

Onions are very weak competitors and usually suffer severe losses from weeds. The challenge of weed control is even greater for organic growers due to the prohibition of synthetic herbicide use. A tool used by organic growers is flame weeding. This is currently only used pre-crop emergence and does not control weeds emerging after the crop. Several types of inter-row weeders, mostly hoes, are available to control weeds post-emergence between crop rows. The options for intra-row weed management are far fewer, and farmers usually have to control these by hand weeding which is generally very expensive, e.g. NZ $3,000-$10,000 per hectare, with labour often difficult to find. Improved economical techniques for intra-row weed management are much needed.

The concept of selective post-emergence thermal weeding was based on the observation that monocotyledons, such as onions, have a growing point that is protected from heat, in the case of onion seedlings, in the soil. This makes them more difficult to kill with weeding techniques that only destroy plant foliage, such as contact herbicides and thermal weeding, than those with their growing points above ground. Organic farmers in some European countries use flaming with burners directed onto each side of the row, but more effective methods for total weed control in onions are lacking (Ascard, 1989; Ascard *et al*., 2007).

A concern with flame weeding is the inconvenience involved in the use of liquefied petroleum gas as a fuel and the danger from 'open' flames as a fire hazard (de Rooy, 1992). During the course of this work, a prototype steam weeder was designed (Merfield 2006; Merfield *et al*., 2009) which uses diesel as the energy source with a fully enclosed combustion process, which addresses the above two issues associated with flame weeders.

This work was undertaken to confirm anecdotal results and determine the best timings for post-emergence thermal weeding in onions. A second objective was to compare the effect flame weeders with steam weeders on weeds and onions at different times during the early growth of the crop and to determine any impacts on onion bulb size and storage quality. This will hopefully open a considerable window of opportunity for more cost-effective weed control in onions.

Methods

General

All field trials were set up on commercial organic farms, Harts Creek Farm at Lakeside, Leeston, Canterbury, New Zealand and Kowhai Farm, at Lincoln also in Canterbury. Onion seed was sown directly onto 1.6 m beds at 40 cm spacing, thus one bed of onions had 4 rows. In all trials, onions were sown in October and harvested in March. The flame weeder used was based on a Hoaf KBL 1.5 (Hoaf Infrared Technology, Netherlands) but with burners redesigned to give a 23% increase in efficiency (de Rooy, 1992). The burners are positioned along the leading edge of a hood 200 mm (high) × 1,400 mm (wide) × 1,200 mm (long) hood. Liquefied petroleum gas is supplied at 2 bar to the burners, which are angled at 45° from the horizontal and point backwards. The flame base is 160 mm from the ground and the flame extends to the soil surface. The flame weeder used 17.5 kg h^{-1} of liquefied petroleum gas, giving a calculated energy output of 174 kW per meter-width. Details of the steam weeder are described in Merfield (2006) and Merfield *et al*. (2009). Briefly, it has a 2,400 mm (long) × 1,750 mm (wide) hood, with the steam and combustion gasses at atmospheric pressure, introduced through a 15 mm slot in the roof at the front of the hood. It had an adjustable internal height set to approximately 100 mm above the top of the onions. The steam weeder used 20.8 kg h^{-1} of diesel, and gave a calculated energy output of 152 kW per meter-width.

Onion growth and weed control were monitored following each thermal weeding. Numbers and percentage cover of the main weed species were recorded and onions were harvested from the middle of each plot (along a 2 m length of 3 rows) in March. In all trials, samples (10 onions) were taken randomly from each plot and kept in a drying shed to determine the effect of thermal treatments on storage quality. These onions were examined in September for signs of rot and the incidence of *Botrytis* spp. and the percentages of these were calculated.

All data were analysed by analysis of variance (ANOVA) and where the F-test was significant, least significant difference (LSD) values were calculated to compare means (P=0.05).

Trial detail

The first (2003-04) and second year (2004-05) trials had four and three replicates, respectively and were arranged in randomised complete block (RCB) designs. Plots were 6 m × 3.2 m (eight rows of onions) in the first year and 5 m × 1.6 m (four rows of onions) in the second. In the first year pre-emergence flame (no steaming) was conducted on 23 October 2003, early post-flaming (onions at the 2-leaf stage (2-L)) was on 10 November 2003 and late-post (onions at the 4-leaf stage (4-L)) on 5 December 2003. In the second year the entire paddock, including the experimental site, was flame weeded by the grower before emergence. Post-emergence thermal weeding treatments were made at 2-L, 3-L and 4-L of onions on 3 November 2004, 15 November 2004 and 15 December 2004 respectively, as well as all combinations described in Table 3. This gave a total of 14 treatments. Flame and steam weeding operations were performed at a speed of 5 km h^{-1}.

In the third year (2005-06) two non-replicated demonstration trials were established on organic farms at Leeston and Lincoln. Large plots were used to better simulate real field situations. Each plot was 20 m (long) × 1.6 m (wide) comprising 4 rows (one bed of onions). The entire paddock was flame weeded before emergence. Flame and steam weeding operations were performed at a speed of 3.5 km h^{-1}. Hand weeding was carried out in January and the time required for workers to complete weeding in each plot was recorded.

Results

First year

There was no significant difference in the number of onions m^{-2} in plots flamed pre-emergence or early post-emergence compared with the control (data not presented). There was slight tip burning of young onion leaves but this was temporary. Plots which received two passes of flame showed 5% loss in crop stand. This was mainly due to the loss of very young onion seedlings (flag stage, only first leaf emerged) and was not statistically significant.

Assessments on 21 November 2003 showed that pre-emergence flaming resulted in 86% weed control compared with the nil treatment. Early post-emergence or plots receiving both pre- and early post-emergence flame were almost weed-free when inspected about two weeks after the operation (Table 1). There was no significant difference in the number of newly emerged weeds among treatments at this time.

Towards the end of the season, weeds, mainly fathen (*Chenopodium album* L.) and clovers (*Trifolium* spp. mostly *Trifolium repens* L.) emerged in the plots, however, differences among flame treatments were still visible. Plots which were flamed post-emergence at 2 + 4-leaf stage (2-L + 4-L) and those receiving three passes of the flame weeder were cleaner than others (Table 1). These plots also had the lowest number of fathen plants with the lowest ground cover by fathen. Plots with only a pre-emergence flame weeding or flaming at 4-L were similar to control plots. No differences in the density or cover of clovers were detected among treatments (data not presented).

Table 1: Weed density and number of new weeds (in brackets) were measured on 21 November 2003, and total weed control score (1 = weedy, 10 = clean) and density and ground cover of fathen measured on 11 February 2004 as affected by flame weeding at different growth stages of onion.

Growth stage	Early weed density[1]	Weed control score	Fathen Density[1]	Fathen Ground cover (%)
Pre-	4.3 (7)	2.0	14	55
2-L	0.5 (2)	3.5	12	46
2-L + 4-L	-[2]	7.3	2	10
Pre- + 2-L	0.0 (0)	4.5	9	44
4-L	-	2.0	17	60
Pre- + 4-L	-	4.5	4	10
Pre- + 2-L + 4-L	-	7.5	2	5
Nil	31.0 (7)	1.0	19	87
$LSD_{(0.05)}$	7.8 (ns)	3.1	8.1	40.5

[1]Density data in number of plants m^{-2}.

[2]- indicates no data available as weed density were measured before thermal weeding at 4-L.

Significant differences were found among treatments in yield and mean fresh weight of onion bulbs (Table 2). Onion yield in the control treatments was 780 kg ha^{-1} showing the ability of weeds to suppress yield. Additionally the onions were very small and most of them were unmarketable. The highest yield and largest onions were obtained from plots receiving three passes of the flame weeder.

Table 2: Bulb yield data for onions harvested on 9 March 2004 as affected by flame weeding at different growth stages.

Growth stage	Yield (t ha^{-1})	Mean onion weight (g)
Pre-	6.04	26.1
2-L	13.55	63.7
2-L + 4-L	16.79	69.3
Pre- + 2-L	12.89	51.3
4-L	8.64	37.5
Pre- + 4-L	11.13	48.9
Pre- + 2-L + 4-L	23.00	81.2
Nil	0.78	7.0
$LSD_{(0.05)}$	7.20	23.7

A number of relationships were explored to describe the effect of weeds on onion yield and quality. A significant regression was obtained between weed density measured one month prior to harvest and onion bulb yield. The regression equation (Figure 1) was:

$$Y = 25.57 - 0.848 \times \text{weed density} \ (R^2 = 0.82)$$

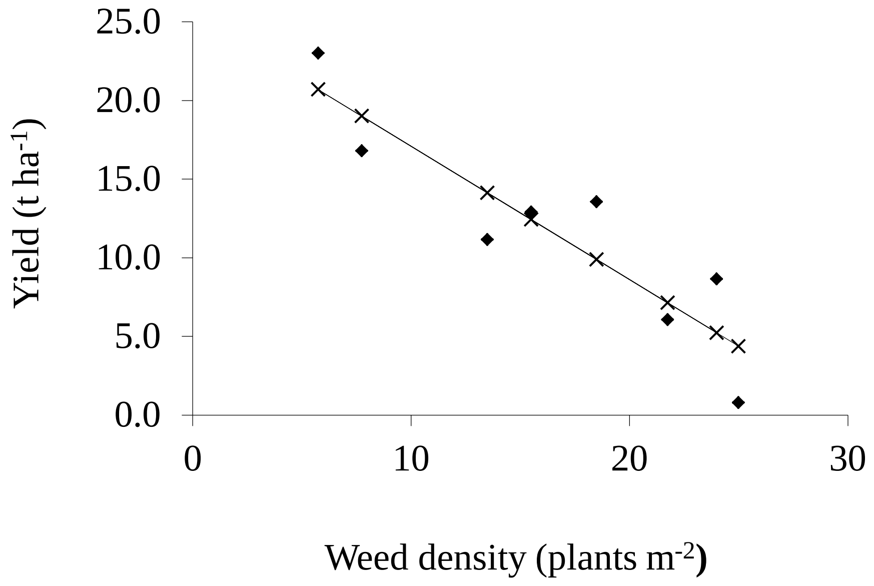

Figure 1: Relationship between total weed numbers measured one month before harvest and onion yield; actual data values (♦) and predicted yield values (×).

Second year

At the 1 December 2004 assessment, two weeks after the thermal treatment at 3-L, control plots had an average of 85 weeds m^{-2} which was significantly higher than any flame or steam weeding treatments (Table 3). The lowest weed numbers were measured in plots which received steam weeding at both 2-L and 3-L.

Two weeks after thermal weeding at 4-L, on 7 January, there was still no significant difference between the two thermal weeding methods; i.e. flame or steam (Table 3). Timing of operation on the other hand, had a significant effect on weed control. On average, the earlier the operation, the better the weed control. Repeated operations resulted in the cleanest plots provided a weeding at 3L was included. For example, thermal weeding at 2L + 4L was no better than a single treatment at 2L (Table 3). This shows the significance of weed control during the 3-leaf stage of onions. Probably, this period coincided with rapid weed growth which became too large to kill at later stages.

Table 3: Weed density (number of weeds m^{-2}) on 1 December 2004 and % weed cover on 7 January 2005 as affected by flame or steam weeding at different growth stages of onion.

	Weed density (number m^{-2})			% Weed cover		
Growth stage[1]	Flame	Steam	Average	Flame	Steam	Average
Control	85	85	85	90	90	90.0
2-L	29	15	22	14	22	18.0
3-L	18	9	13.5	24	27	25.5
4-L	-	-	-	20	50	35.0
2-L + 3-L	14	5	9.5	5	5	5.0
2-L + 4-L	-	-	-	13	23	18.0
3-L + 4-L	-	-	-	4	2	3.0
2-L + 3-L + 4-L	-	-	-	4	1	2.5
$LSD_{(0.05)}$			17.2			27.0

[1]All plots were flame treated pre-emergence.
[2]- indicates no data available as weed density were measured before thermal weeding at 4-leaf stage.
For weed density, P-timing = 0.001, P-method = 0.113, P-interaction = 0.09.
For % weed cover, P-timing = 0.007, P-method = 0.18, P-interaction = 0.57.

A visual assessment in January did not show any significant difference between treatments on onion vigour (data not presented). Highly significant differences were found in onion yield and bulb size between the timing of thermal weeding indicating a strong effect of onion growth stage and weeds on the success of the operation. There was no difference between flame and steam methods and there was no interaction between methods and timing of operation. As an average of both methods, the highest onion yields were obtained in plots which received thermal weeding at 2L + 3L, 3L + 4L, or 2L + 3L + 4L (Table 4). Again, if 3-leaf stage was not included in the thermal weeding, the operation was less successful and the yield was significantly lower. The results also showed that a single thermal weeding was not sufficient to combat weeds.

Average weight of onion bulbs was the lowest in plots with only one pass of thermal weeding at 4L followed by those with a single pass at 2L (Table 4). A single pass at 3L produced larger onions than two passes at 2L + 4L. Small onions were a direct result of weed competition and this again shows the importance of timing in weed management in onion.

Table 4: Bulb yield and mean weight of onions on 3 April 2005 as affected by flame or steam weeding at different growth stages of onion.

	Yield (t ha^{-1})			Mean weight (g)		
Growth stage[1]	Flame	Steam	Average	Flame	Steam	Average
2L	9.17	5.10	7.13	36.0	39.4	37.7
3L	11.33	11.10	11.22	42.6	42.3	42.4
4L	7.80	2.50	5.15	27.1	10.0	18.6
2L + 3L	18.57	23.33	20.95	69.3	68.8	69.1
2L + 4L	11.67	9.73	10.70	35.9	33.5	34.7
3L +4L	23.67	24.17	23.92	67.9	65.8	66.9
2L + 3L + 4L	18.33	22.33	20.33	54.2	66.9	60.6
$LSD_{(0.05)}$			8.27			28.0

[1]All plots were flame treated pre-emergence.
For onion yield, P-timing = 1.68×10^{-07}, P-method = 0.83, P-interaction = 0.47.
For mean weight of onions, P-timing = 3.44×10^{-05}, P-method = 0.85, P-interaction = 0.84.

Observations on onion storage ability were made through the winter. The percentage of rotten onions in samples stored for six months varied from nil to 10%. There was no significant difference between treatments (data not presented).

Third year

Weed control was improved when thermal weeding was made early. Two passes of either flame or steam weeder gave the best control provided that one pass was at the 3-leaf stage (Table 5). The trial was not replicated, but yield results were comparable to those of the replicated experiments in previous years. For example, the highest yields were obtained when either flame or steam weeding was carried out at 3L + 5L.

Table 5: Weed control score (1 = weedy, 10 = clean) on 20 December 2005 and onion bulb yield on 24 February 2006 as affected by flame or steam weeding at different growth stages of onion in demonstration plots.

	Weed score		Yield (t ha^{-1})	
Growth stage[1]	Flame	Steam	Flame	Steam
Control	1	1	21.5	22.0
3 L	4	2	20.3	21.3
4 L	2	1	18.5	16.9
5 L	1	1	23.5	19.8
3L + 5L	6	5	26.6	27.4
4L + 5L	4	2	19.7	21.0

[1]All plots were flame treated pre-emergence.

The time to hand weed plots was similar among control plots and treatments receiving one pass of either flame or steam at either 4L or 5L (Table 6). However, one pass of either weeder at 3L resulted in an approximately 50% saving in hand weeding time. With two thermal weedings at 3L + 5L, the time saving was approximately 80% giving a saving in gross labour costs of over $3,950.

Table 6: Time taken for hand weeding and saving in labour cost following flame and steam treatments at different growth stages of onion in demonstration plots.

	Time as % of control		Gross saving in labour $[1]	
Growth stage	Flame	Steam	Flame	Steam
Control	100	100	0	0
3 L	49	58	2550	2100
4 L	110	110	0	0
5 L	113	95	0	250
3L + 5L	18	21	4100	3950
4L + 5L	52	46	2400	2700

[1]Based on an average cost of $5,000 ha^{-1} for hand weeding, this can be higher in weedy fields.

Storage

In all experiments described, onion storage quality was not affected by the treatments. For example, in year three at Leeston, three months after harvest no rotten onions were observed in samples from flamed or steamed plots, while 1.5% of onions from control plots showed signs of rot. Onions from Lincoln showed similar results with no rot observed in flamed onions and 1.3% rot in the control. At the second assessment, six months after harvest, only a few onions had symptoms of neck rot. Examination by microscope revealed *Botrytis allii* in the onion scales. The results indicate there was no increase in the incidence of neck rot as a result of post-emergence flame or steam operations.

Discussion

Onions showed serious yield loss due to weed competition. Yield losses up to 33% and 66% were calculated when 10 or 20 large weeds per m^2 were present (Figure 1). The weed density data were recorded towards the end of the season when weeds were very large. The relationship may be different at early growth stages. Nevertheless, Figure 1 illustrates the vulnerability of onions to weed competition and the importance of weed control.

Plants are killed by thermal techniques, such as flame or steam because their cells are ruptured by the heat. The tolerance of thermal treatment by some plant species has been attributed to protective layers like wax, cuticle and hairs or the ability to re-grow due to having their growing points below the ground (Hatcher and Melander, 2003). Onions have such attributes and are therefore suitable candidates for post-crop emergence thermal weeding. The results of these experiments show that onions have high resistance to thermal weeding and can tolerate even three post-emergence flame or steam treatments. Similarly, Ascard (1989) found that in direct-sown onions, flaming pre-emergence and when the crop was 15 cm high did not adversely affect yield. In these experiments, onions lost a leaf, but later recovered and in some treatments produced very good yields.

The results over three years consistently showed that the critical time for post-emergence thermal weeding is the 3-leaf stage of onions and a follow-up pass at the 5-leaf stage to obtain additional weed control. Most organic onion growers already employ a pre-emergence flame weeding. Thus, three passes, one pre-emergence, and two post-emergence at the 3-leaf and 5-leaf stages may be needed depending on weed pressure. The success of thermal weeding depends on the species and size of weeds present and knowledge of the local weed flora and their susceptibility is essential (Sivesind *et al*. 2009).

Comparing the two thermal weeding implements gave encouraging results for a locally built diesel-operated steam weeder as a more economic and user-friendly tool for weed control in organic systems. The absence of biological and statistical differences in weed control between flame and steam is consistent with a previous comparison of the same thermal weeders (Merfield, 2006). However, the flame weeder energy output was 14% higher per meter of working width. This indicates that steam weeding is possibly slightly more effective than flame as it gave the same result but used less energy. However, assuming comparable effectiveness, the steam weeder provides a safer and more convenient option for growers.

This work shows that thermal weeding has more potential for weed management in onions than is currently utilised. Another question is whether the shock received by the onions during flame or steam operations affects bulb quality. No increase in rotting was found in onions after two passes of either flame or steam. Unlike other mechanical damage, there is the potential for thermal treatments to reduce the incidence of neck rot caused by *B. allii*. This technique is currently under investigation, as an onion harvesting aid (Merfield, unpublished data).

In the absence of damage to onions from thermal weeding, judgment on the benefits of this operation will be a financial question. To control late-emerging weeds, some farmers use other weeding operations such as inter-row hoe and hand weeding. The additional cost of these operations should be carefully considered for economical return. Table 7 provides a range of costs of non-chemical weed control operations in onion. The wide range for hand weeding costs is because the cost of hand weeding is related to the populations, size and species of weeds which are very different among years and sites. Hand weeding is a costly operation, it is therefore necessary to ensure it is financially justified. A sensible question then would be whether it is possible to reduce the weed control cost by replacing one of the hand weeding operations with an inter-row hoe or thermal weeding.

Table 7: Weed control operations in onions and their costs ($ ha^{-1}).

Weed control operation	Cost range	Number of passes required	Typical cost of operation
Flame or steam	120-250	3	600
Inter-row hoe	80-100	4-6	500
Hand weeding	3,000-10,000	1-2	5,000

Conclusion

This work demonstrated that thermal weeding has considerable potential to improve weed management in onions, while reducing overall weeding costs. Further research and farm evaluation are necessary to build up a more comprehensive understanding of the technique and to ensure that it is sufficiently reliable as a standard commercial technique.

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