

# **Final Report for Project**

**“Development of technical information for growers for the use of propane for steaming as an alternative to post-emergence herbicides in orchards, vineyards and vegetables”**

**Prepared By**

**Ramon G. Leon, Ph.D.**

Project Director

Horticulture and Crop Science Department  
California Polytechnic State University

San Luis Obispo, CA  
2006

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## **Executive Summary**

A series of experiments were conducted to evaluate the effectiveness of steaming for post-emergence weed control, and to generate technical information that can be used to advise growers about how to best use this new technology.

It was determined that steaming has the potential to provide proper weed control in commercial agricultural operations, but there are technical details that must be considered to ensure successful results. First, it was observed that not all weed species are equally susceptible to steaming, and those that have thick and/or succulent (high water content) leaves are more likely to be less injured. Second, weeds must be steamed before they reach 4 inches of height. Larger plants could survive and recover, but they will likely reduce their growth rate as a result of the steaming. Third, steaming must be conducted at a maximum speed of 2 mph when the steam temperature is 400 C.

The studies were conducted with the Stinger, which is an equipment designed and manufactured in Australia for post-emergence weed control. This was done to assess the potential for introducing this type of technology into California agricultural production. The Stinger showed promising weed control in conventional and especially organic farms, but modifications to the existing equipment will greatly improve the applicability of the technology to different scenarios. Growers expressed their preference for equipment that will allow steaming at a speed of at least 4 mph and covering a wider area. There is a clear need for steamers that are more versatile allowing growers to vary the area of steaming and the type of crop in which the equipment can be used, as they can do with other equipments for weed control. In addition, it will be important to increase the temperature of the steam or the rate of steam release to allow the use of higher speeds without reducing weed control. Once these technical modifications are made, steaming will likely be an important part of weed management programs in many different cropping systems.

## **Introduction**

Heat has been used as an alternative to post-emergence herbicides to kill weeds for several years. The most common approach has been to burn weeds with fire using flammers. This approach has not been widely accepted by farmers because inconsistent control and the high risk for wild fires and crop injury. D. J. Batchen, Pty. Ltd., an Australian company, recently introduced to the USA a device called the Stinger that is designed to kill weeds after their emergence using steam. This equipment uses propane as fuel to generate the heat necessary for producing the steam. This new technology has a great potential to improve weed management in many crops including vineyards, orchards, vegetable, and row crops. The advantage of this equipment is that it quickly kills weeds, similarly to post-emergence herbicides, but there is no residual activity. In addition, compared to mechanical weed control tactics, there is no soil disturbance, so soil erosion is dramatically reduced, and soil moisture conservation is greatly enhanced.

Proper and clear recommendations for the use of a new technology are a key component for its successful introduction and acceptance in agriculture. Because steaming for weed control is new, there is no technical information that growers can follow in order to optimize the use of this technology based on the weeds they have and the characteristics of their crops and production practices. For this reason, several studies were conducted to test the viability of the use of steaming for post-emergence weed control of different weed species and to generate part of the information that can be used as technical recommendations for growers. The present report discusses the results of those studies.

## **Results**

### ***Effect of speed on steaming efficacy for post-emergence weed control***

Greenhouse and field trials were conducted to determine the optimum speed for proper weed control using steaming. These trials were done by steaming areas covered with vegetation containing different weed species and individuals of different sizes at different speeds (1-5 mph). In general, it was evident that above 2 mph plant injury was below 50% even for small plants (<4 inches tall). In addition, many of the plants showing injury recovered within a week. Steaming at 3-5 mph provided almost no weed control. The best control (70-90%) was observed at 1 and 2 mph, but at the latter a higher variability in controlled was observed. For this reason, for the rest of the experiments, the steaming speed was 1.5 mph.

As it will be explained later, the chosen speed (1.5 mph) allowed high levels of weed injury and in some cases acceptable control, but this speed was considered unpractical for most growers when compared with herbicide application and cultivation control speeds. An informal consultation was done asking local growers, certified Pest Control Advisors, and Farm Advisors from the University of California Cooperative Extension System (UCCE) which speed they thought was necessary to make steaming a viable option for California Central Coast agriculture. There was consensus indicating that if steaming could be done at 4 mph with at least 80-90% weed control, they would seriously consider implementing this technology as part of their integrated weed management program. The main reason for this requirement was that

below 4 mph, most growers or farm/ranch managers would not be able to cover the entire area of their farms in a timely fashion.

### ***Effect of ground slope on steaming efficacy for post-emergence weed control***

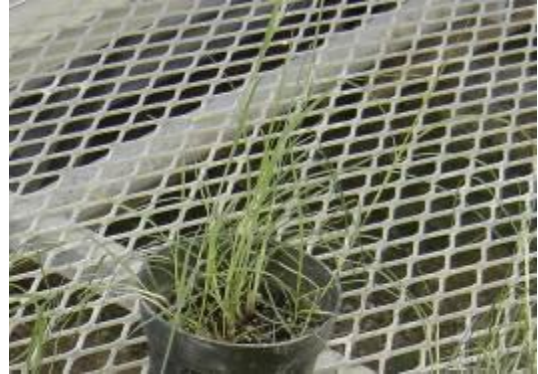
This experiment was not conducted because after a few tries to run the Stinger in vineyards with different slopes (2-15%), it became evident that this equipment was not designed for such conditions. Some of the observations made were that an uneven surface caused the “hood” of the Stinger to bounce, and this translated in uneven steaming.

Depending on the position of the hood with respect to the slope, the outer side of the hood was sometimes too high above the weeds to cause enough injury or too low which pushed the hood towards the ground reducing steam flow causing the equipment to automatically shut down due to overheating. This occurred even in flat fields (less than 2% slope) when the ground was not graded uniformly.

### ***Effect of plant size on steaming efficacy for post-emergence control of weed species with different morphological characteristics***

Greenhouse experiments were conducted to test the importance of plant size on steaming efficacy for weed control. This was done with seven weed species differing in life cycle, morphology and growth habits to determine what type of traits can better predict the weed response to steaming. The species chosen were:

**Bermudagrass** (*Cynodon dactylon*; Poaceae) is a perennial grass considered an aggressive weed in annual and perennial crops. Its leaves are thin, glabrous (no hairs) and with a tendency to grow horizontally.



**Perennial ryegrass** (*Lolium perenne*; Poaceae) is a perennial grass that is found commonly in perennial crops in California. This species has glabrous leaves that are narrow and show an erect growth. This grass although is considered a weed in agricultural settings is also used as turf.



**White clover** (*Trifolium repens*; Fabaceae) is a creeping perennial weed that is very difficult to control in lawns. Its plants are usually 4-12 inches tall; the leaves have three oval leaflets approximately 0.25 to 0.5 inches wide, and they grow horizontally.



**English daisy** (*Bellis perennis*; Asteraceae) is a perennial weed that grows forming a basal rosette and is commonly found in gardens and lawns. The leaves are elongated, wide and have thin short hairs on the blade.



**Bristly oxtongue** (*Picris echioides*; Asteraceae) is a biennial weed that is aggressive in orchards and vineyards. The plants of this species grow the first year as a rosette, and the second year grow vertically reaching up to 3 feet. The leaves are long (2-5 inches) and wide (0.5-1 inch) and are covered with hard thick hairs.



**Common mallow** or cheeseweed (*Malva neglecta*; Malvaceae) is an important annual weed that is commonly found throughout California agricultural fields. In the Central Coast, it is especially problematic in vegetable fields and vineyards because there are few effective herbicides and mechanical control tools against it. The plants grow vertically up to 5 feet and the leaves are round growing usually horizontally. The size of the leaves vary, but at early vegetative stages their diameter is 0.2 to 1 inch.



**Common purslane** (*Portulaca oleraceae*; Portulacaceae) is one of the most common annual weeds in the world. It grows prostrate forming wide mats that cover the ground. This plant does not compete for light, but it competes very well for water and nutrients. Its leaves are oval, 0.1-1 inch long, 0.1-0.25 inches wide, very thick and succulent, and they grow horizontally.



After species selection, seeds from all species were planted in pots with sterile soil mix and watered constantly. The plants were planted at three different times to have three growth/developmental stages at the time of steaming. The developmental stages were:

**Seedling:** plants were <2 inches tall and showed cotyledons and/or 2 true leaves.

**3 to 6 true leaves:** plants were 2-6 inches tall. The grass species started to form tillers and the broadleaf species showed a few branches.

**Vegetative stage:** plants were > 6 inches tall, showing more than 6 true leaves.

When the plants reached the desired developmental stages, they were steamed at 400 C driving the Stinger at 1.5 mph with the steam jet output being at 2-3 inches above the canopy of the plants (Figure 1). Half of the plants for each developmental stage were treated and half were not to be used as controls.



**Figure 1.** Steaming several weed species using the Stinger.

The experiment was arranged as a completely randomized design with six treatments (combinations of three developmental stages and two steaming treatments: with and without) and four replications (Figure 2). The experiment was conducted twice to confirm reproducibility of results.



**Figure 2.** Arrangement in the Greenhouse of experiment testing for steaming effect on several weed species.

Visual tissue injury (stunting, chlorosis and necrosis) and plant height were measured 1, 3, 7 and 14 days after treatment (DAT). Fourteen DAT the plants were harvested by clipping their above ground structures. The plants were then dried in an oven for 2 days and weighed.

Steaming injury symptoms were clearly observed 1 DAT, but the greatest damage was recorded 3 DAT followed by a slow recovering period (Figure 3 and Table 1).

The weed species differed dramatically in their response to steaming ranging from 23 to 81% injury. It must be highlighted that for a herbicide to be considered effective it must cause 95 to 100% injury. Therefore, the levels of injury observed were very low. In addition, the wide range of injury shows the limitations of the technology for broad spectrum weed control. It is interesting that the grasses and common mallow were the species showing the highest injury levels (>60%), while species showing prostrate growth suffered less (23-37%).



**Figure3.** Typical injury shown by weeds such as english daisy (up) and perennial ryegrass (down) 3 days after steaming. The leaves that were exposed to the steam became necrotic and died. Smaller leaves that were shaded by the larger leaves avoided the steam thus surviving and staying green.

**Table 1.** Effect of steaming on tissue integrity of seven weed species. The plants were steamed at three developmental stages: seedling, 3-6 true leaves and early vegetative. Visual injury was measured at 1, 3, 7 and 14 days after treatment (DAT).

Treatment	Visual Injury (%)			
	DAT			
	1	3	7	14
Bermudagrass	72 a	81 a	71 a	65 a
Bristly oxtongue	39 bcd	37 bcd	31 cd	26 bcd
Common mallow	60 ab	62 ab	59 ab	31 bcd
Common purslane	25 d	23 d	24 d	9 d
English daisy	31 cd	34 cd	27 d	21 cd
Perennial ryegrass	63 ab	68 a	56 abc	48 ab
White clover	53 abc	56 abc	43 bcd	37 bc
Seedlings	54 a	59 a	49	54
2-6 true leaves	49 ab	48 ab	43	49
Early vegetative	40 b	45 b	38	40

\* Numbers with the same letter within columns are not statistically different based on Tukey's test ( $\alpha = 0.05$ ).

Originally, it was hypothesized that species with wide, long and horizontal leaves would be very susceptible to steaming because they would have a larger contact surface area with the steam. Conversely, species with narrow and vertically growing leaves would be more tolerant because the reduced contact surface area. However, the opposite results were observed. It seems that thickness is more important than leaf shape or angle to determine tissue injury in response to steaming. Linear regression analysis showed a negative relationship between leaf thickness and injury ( $r^2 = 0.6$ ,  $P < 0.05$ ). Thus, common purslane, which was the species with the thickest most succulent leaves studied, showed the lowest levels of injury and bermudagrass that had the thinnest leaves suffered the highest injury.

Although the levels of visual injury were not as high as expected, steamed plants suffered significant reduction in height and biomass in comparison with untreated plants (Table 2). The different weed species suffered 30-50% reductions in growth ( $P < 0.0001$ ) suggesting that the initial injury caused by the steam stressed the plant enough that full recovery was not achieved at 14 DAT.

The developmental stage and plant size at the time of steaming was important to increase the effectiveness of the treatment. The highest injury levels and reduction in weed growth were achieved when the plants were at the seedling stage or had 2-4 true leaves, or their height was less than 6 inches. Larger plants or at later developmental stages showed less tissue injury due to a "shading" effect in which the leaves at the top of the plant or in the outer layers of the canopy that were directly exposed to the steam acted as shields protecting leaves located lower or inside the canopy (Figure 3). In addition, older plants with lateral growth (i.e. tillers in grasses

and branches in dicots), could produce new growing axes if the apical meristem (main growing point) was damaged.

**Table 2.** Effect of steaming on the growth of seven weed species. The plants were steamed at three developmental stages seedling, 3-6 true leaves and early vegetative. Plant height and biomass was measured 14 days after treatment and are expressed as a percent of the untreated control plants.

Treatment	Height (% based on comparison to untreated plants)	Biomass (% based on comparison to untreated plants)
Bermudagrass	66 b	54
Bristly oxtongue	88 ab	69
Common mallow	80 ab	71
Common purslane	97 a	64
English daisy	79 ab	61
Perennial ryegrass	69 b	71
White clover	69 b	59
Seedling	75 b	60 ab
2-6 true leaves	72 b	54 b
Early vegetative	86 a	73 a

\* Numbers with the same letter within columns are not statistically different based on Tukey's test ( $\alpha = 0.05$ ).

### ***Effect of plant size on steaming efficacy for post-emergence control of weed species in a vineyard in the Central Coast of California***

A field experiment was conducted in a Vineyard in Paso Robles, CA in 2006 to determine the effectiveness of steaming for post-emergence weed control at a commercial scale in a wine-grape production operation. The main goals of the experiment were to assess the level of weed control provided by the Stinger and how this control would impact grapevine yields.

The experiment was conducted in a vineyard planted with a Zinfandel variety, which is very common in the Central Coast. The treatments were:

**Conventional Herbicide (CH):** the grapevine row was sprayed in January with a tank mix of oxyfluorfen at 0.75 lbs/acre and glyphosate at 0.69 lbs/acre for pre-emergent control.

**Steaming 1 pass (S1):** the weeds were steamed once when they reached an average height of 4-6 inches tall. Steaming was conducted passing the Stinger at 1.5 mph on top of the weeds. The height of the steam outlet was 6 inches from the ground.

**Steaming 2 passes (S2):** the weeds were steamed when they reached an average height of 2-3 inches tall (Figure 4). This was done twice during the spring. Steaming was conducted in the same way than in S1.

**Weedy control (WC):** in this treatment, no weed control was conducted during the growing season.

The experiment was arranged as a randomized complete block design with three replications, and each experimental unit was a row with approximately 50 vines. Visual weed control was determined 3 and 7 days after treatment. In addition, weed density and grapevine canopy were determined once a month. Finally, at the end of the growing season weed biomass per area, grapevine pruning weight and fruit yield were evaluated.



**Figure 4.** Steaming with the Stinger under a grapevine row in Zinfandel vineyard in Paso Robles, CA.

The level of weed control showed by S1 and S2 was equivalent to CH all ranging between 85 and 95%. These results contradict the results obtained in the greenhouse experiments. We believe that in the field, the weeds were in a relatively dry and warm environment and experiencing stressful conditions. Thus, after being steamed, the weeds were depleted of energy and unable to recover. Conversely, in the greenhouse, the plants were growing in an optimum growing environment, which likely allowed them to survive the steaming and recover. Therefore, to increase steaming effectiveness under field conditions it seems important to properly time the steaming event with a stressful environment for the weeds. In practical terms, this means not to steam weeds soon after rainfall, irrigation or fertilization if the weeds are beyond the early vegetative stage.

The steaming treatments did not reduce the number of weeds that were competing with the grapevines, but they were able to reduce weed biomass approximately 60% to almost the level of weed biomass allowed by CH treatment (Figure 5 and Table 3). This decrease in weed growth is probably due to the reduced growth rates that weeds show after being steamed, as was observed in the greenhouse experiments. On the other hand, grapevine row was not

affected by the different treatments, and no differences in pruning weight or grape yield were detected. This was not a surprising result because it had been previously seen that grapevines are capable of tolerate high levels of weed competition without reducing yield, at least in the short term.



**Figure 5.** Weed populations in vines treated with a conventional pre-emergent herbicide (left), with steam (center), and no weed control (right).

**Table 3.** Effect of different weed control treatments on weed grapevine growth parameters, in a Zinfandel vineyard in Paso Robles, CA.

Treatment	Weed density plants m <sup>-2</sup>	Weed Biomass g m <sup>-2</sup>	Pruning Weight kg per vine	Grape Yield kg per vine
Conventional Herbicide	48 a*	49 a	1.4	8.9
One pass steaming	204 b	197 a	1.3	8.3
Two passes steaming	205 b	196 a	1.1	6.9
No weed control	206 b	428 b	1.4	7.3

\*Numbers with the same letter within columns are not statistically different based on Tukey's test ( $\alpha = 0.05$ ). Columns without letters had no statistical differences between treatments.

### ***Future needs for steaming for weed control***

Steaming equipment design and versatility: Most spraying and cultivation equipments used in vineyards cover two rows per pass, and they can be run at 3-5 mph. However, the Stinger steams only one row per pass at 1.5 mph, so the time for weed control using the Stinger is at least 4 times higher than using conventional weed control approaches. All growers consulted clearly stated that they would like to see a unit that will steam at a speed of at least 4 mph.

Organic production is the fastest growing agriculture activity. Every year more fruit and vegetable growers are producing organically because they can increase their profits despite the extra effort that this type of production represents compared with conventional agriculture. Originally, most organic growers were small and relying intensively on hand labor. Currently, large farms and corporations are transitioning to organic production too, but based on the size of their operations they cannot rely on hand labor for managing their fields. Therefore, more large scale-mechanized practices are required. Cultivation and flaming are the most common mechanized approaches to control weeds in organic systems. This is because they allow weed killing at a relatively high speed (2-5 mph for flaming and 4-10 mph for cultivation) and covering a wide area per pass (4-6 beds or 13-20 ft). The use of steaming has called the attention of several organic growers because the higher propane consumption efficiency compared to flaming, but they need a steaming unit that covers at least 2 to 4 beds per pass. We tested the Stinger in organic vegetable fields steaming one bed per pass (Figure 6). It was determined that the Stinger used 40% less propane than the farm's flamer while providing equivalent control and covering a larger area. These results were considered as very positive by the farm manager, but he expressed concerns about the reliability of the equipment because it shut down several times during the test.



**Figure 6.** Steaming beds before crop transplanting in an organic vegetable farm using the Stinger.

Throughout the discussions with growers, there was a recurrent theme, which was the need for a more versatile design of the Stinger or any other steaming unit. It was proposed that the water and propane tanks could be directly attached to a tractor and the steaming unit should be independent and able to be moved to steam sideways, backwards, rows, beds or flat areas, and that the width of the steaming area could be controlled similarly to what growers do with cultivation and spraying equipments.

## **Recommendations and restrictions for the use of steaming as post-emergence weed control**

- 1) Steaming must be done when weeds are no more than 4 inches tall.
- 2) When using the Stinger generating steam at 400 C, do not steam at speeds higher than 2 mph.
- 3) Increasing steaming speed will increase the need for several steaming passes.
- 4) In areas with variable or erratic weed emergence patterns 2 to 3 steaming passes separated at least two weeks from each other can increase long season weed control.
- 5) Weed species with thick or succulent (high water content) leaves might not be properly controlled using steaming.
- 6) Do not steam weeds soon after rainfall events, irrigation, or fertilization, unless the weeds are at the seedling stage.
- 7) If weed populations are visibly dense, steam before the taller weeds can shade the smaller ones to make sure all weeds will be directly exposed to the steam.
- 8) Perennial weeds will survive steaming if they have developed structures such as rhizomes, stolons, tubers, or deep rootstocks. In these cases, steaming must be implemented repeatedly in combination with other practices such as cultivation.

## **Conclusions**

- Steaming has the potential to provide commercially acceptable post-emergence weed control.
- Different weed species have different levels of tolerance to steaming based on their morphology and life cycles. For this reason, depending on the weeds present and their developmental stage and height, the efficacy of steaming weed control might vary considerably.
- If steaming is conducted when weeds are between the seedling stage (cotyledons) and 2-4 true leaves, most weeds should be properly controlled.
- The benefits of steaming for weed control are not limited to killing weed tissue, but also to significantly reduce the growth of surviving weeds.
- Future models of the Stinger or any other steaming equipment for weed control should allow steaming at speeds of at least 4 mph. This can be achieved either by increasing steam temperature or steam release rates.
- Steaming units should have a versatile design that enables their use in different agricultural production systems and not only orchards and vineyards.

***Contact information for growers and farm managers that were consulted about their opinion on the use of steaming for weed control***

**Jerry Mahoney**

Production Manager Cal Poly Organic Farm, San Luis Obispo, CA.  
Tel. (805) 878-1744

**Jake Terrel**

Production Manager Sunny Brook Vineyard, Paso Robles, CA.  
Tel. (805) 674-8347

**John Winstead**

Production Supervisor Gallo Vineyards, Paso Robles, CA.  
Tel. (805) 238-1984

**Julian Malone**

Pest Control Supervisor Sheid Vineyards, San Ardo, CA.  
Tel. (805) 704-5886

**Central Coast Vineyard Team (CCVT)**

Paso Robles, CA.

Tel. (805) 369-2288

CCVT has an extensive list of growers that attended the different field days and that were interested in the Stinger. Due to privacy constraints, the names and contact information of those growers must be requested directly to CCVT.