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Flame Weeding Effects on Several Weed Species

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Flaming can be an effective nonselective, nonchemical method of weed control. It has been more effective against broadleaf weeds than grasses. Experiments were conducted with a conveyor bench burner apparatus to evaluate flaming to kill broadleaf and grass seedlings at the 0- to 2- and 2- to 4-leaf stages. Most 0- to 2-leaf green foxtail seedlings were killed when flamed at 2, 4, and 6 km/h conveyor speed. A few plants survived when flamed at 8 km/h. Green foxtail seedlings at the 2- to 4-leaf stage were more tolerant to flaming than 0- to 2-leaf green foxtail, and substantial numbers of plants survived at all flaming speeds except 2 km/h. Barnyardgrass was more tolerant to flaming than green foxtail, and many 0- to 2- and 2- to 4-leaf seedlings survived after flaming. However, fresh weight of the live plants at 14 d after treatment was reduced. Some large crabgrass plants survived flaming at both growth stages. Flaming at 2 km/h reduced seedling number and fresh weight, but there was significant regrowth. Common ragweed was more susceptible to flaming at the 2- to 4-leaf stage than at the 0- to 2-leaf stage. Redroot pigweed and common lambsquarters were susceptible to flaming at both 0- to 2- and 2- to 4-leaf stages.
Nomenclature: Redroot pigweed, *Amaranthus retroflexus* L. AMARE; Common ragweed, *Ambrosia artemisiifolia* L. AMBEL; Common lambsquarters, *Chenopodium album* L. CHEAL; Large crabgrass, *Digitaria sanguinalis* L. DIGSA; Barnyardgrass, *Echinochloa crus-galli* L. ECHCG; Green foxtail, *Setaria viridis* L. SETVI.
Key words: Alternative weed management, flaming, flame weeding, nonchemical weed control, organic weed control.

Flame weeding is the most common thermal weed control method in agriculture (Ascard 1995b). This technique uses propane burners to generate combustion temperatures of up to 1,900 C, which raises the temperature of the exposed weed leaves very rapidly and the leaves are killed without burning (Ascard 1995b). Heat exposure denaturizes plant proteins, which results in loss of cell function, causes intracellular water expansion, ruptures cell membranes, and finally desiccates and kills the weeds, normally within 2 to 3 d (Campbell 2004; Diver 2002; Heiniger 1999; Rahkonen and Jokela 2003). After its almost complete disappearance in the 1970s, flame weeding has regained interest for nonselective weed control in organic production (Ascard 1995b).

The main advantages of flame weeding are the lack of chemical residues in the crop, soil, or water; the lack of herbicide carry-over the next season; the wide spectrum of weeds controlled with no possibility of developing resistance to flaming; and compatibility with no-tillage production techniques (Ascard 1995b, 1998; Heiniger 1999, Mojžiš 2002). The main disadvantages of flame weeding are the lack of residual weed control, the lack of selectivity for crop safety, low speed of application, increased application costs, and applicator safety (Ascard 1995b).

The growth stage of the weeds at the time of flaming determines weed sensitivity to heat. The stage of growth of the weeds establishes the kind and degree of protective layers, the lignification level, and the location of growth points. Flaming is most effective on most weeds at an early growth stage (Ascard 1995a, 1998; Campbell 2004; Diver 2002; Mojžiš 2002).

In addition to the growth stage of the weeds, the efficacy of flaming is determined by the amount of heat transferred from the burner and the duration of exposure of the weeds to the heat (Ascard 1998; Heiniger 1999). The amount of heat transferred by the flamer to the weeds is determined by the number of burners for a given working width, the nozzle size, and the gas pressure. The exposure time is determined by application speed. Ascard (1998), found a strong positive correlation ($r^2 = 0.99$) between the combination of temperature and exposure (temperature sum) and weed control. The amount of heat transferred to the weeds and the exposure time are combined into a figure called propane consumption per hectare (Mojžiš 2002), or propane consumption, in kilograms per hour, per unit working width in meters (Ascard 1998). This is a convenient figure for comparing flame treatments.

Flame weeding usually is classified as pre-emergence flaming or postemergence flaming. Pre-emergence flaming kills the first flush of weeds after seeding the crop. This often is the largest group of weeds to germinate during the season. If there is no soil disturbance after initial tillage, new weed emergence is reduced.

For fast-growing crops, pre-emergence flame weeding can provide sufficient weed suppression to allow the formation of full crop canopy, which impedes later weed emergence. Later flushes of weeds can cause serious competition for slow-growing crops. Pre-emergence flaming usually does not provide sufficient weed control to avoid yield reduction, because it controls only a fraction of the weeds that emerge during the cropping season.

Postemergence flaming consists of directed or shielded flaming of weeds after the crop has emerged. Timing of application is important to avoid crop damage (Campbell 2004). For heat-resistant crops such as cotton, corn, and sugarcane, flame can be directed to the base of the plants at some growth stages. This technique, called selective flaming, controls intrarow weeds (Diver 2002). For heat-sensitive crops, postemergence flaming can be applied using a covered flamer to protect the crop from the intense heat (Ascard 1995b). This technique, also known as parallel flaming, controls the weeds between the rows.

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Table 1. The effect of flaming barnyardgrass seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage: Live plants, Initial	0- to 2-leaf stage: Live plants, 14 DAT	0- to 2-leaf stage: Fresh wt., 14 DAT	2- to 4-leaf stage: Live plants, Initial	2- to 4-leaf stage: Live plants, 14 DAT	2- to 4-leaf stage: Fresh wt., 14 DAT
	no./flat	no./flat	g/flat	no./flat	no./flat	g/flat
2 km/h	16.0 a	20.4 c	2.45 b	24.9 a	43.3 ab	6.85 b
4 km/h	17.6 a	34.1 b	4.21 b	25.6 a	49.9 ab	10.63 b
6 km/h	15.8 a	32.5 b	3.65 b	25.3 a	52.8 a	15.01 b
8 km/h	20.1 a	43.4 a	4.57 b	23.1 a	47.6 ab	16.15 b
Untreated	20.5 a	26.8 bc	28.22 a	23.9 a	38.9 b	84.36 a
LSD $_{(0.05)}$	NS	8.7	11.02	NS	11.0	11.19
CV	40.5	27.0	33.8	32.9	23.2	17.8

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

The susceptibility of weeds to thermal weed control is determined by several factors. The developmental stage of the weed is probably the most important factor; seedlings with the shoot apex exposed are more susceptible to flame weeding than older seedlings where the shoot apex might be protected by surroundings leaves, or where axillary buds might have developed. In addition, older seedlings have a larger surface area and larger biomass, which requires higher temperature and longer exposure to achieve control. In general, broad-leaved plants are more susceptible to heat than grasses because grasses have a sheath that protects the growing point. Weeds with growing points below the soil surface often regrow after a flaming treatment. Annual weeds are more susceptible to flame weeding than biennials and perennials (Ascard 1995a, 1998; Diver 2002; Mojžiš 2002).

The objectives of this study were (1) to determine the temperature and speed of application required for a covered flamer to control specific weeds and (2) determine the optimal growth stages of these weeds for maximum control with flaming applications.

Materials and Methods

Experiments were conducted to determine the influence of weed developmental stage and time of exposure to heat on weed control efficacy. Weeds were moved at different speeds through a variable speed conveyer stationary flamer that was built in the Department of Agricultural Engineering at Michigan State University. The experiments were conducted at the MSU Horticulture Teaching and Research Center, Holt, MI.

Three grass and three broadleaf species were used in this study: green foxtail, barnyardgrass, large crabgrass, redroot pigweed, common ragweed, and common lambsquarters. Five hundred seeds of each species were counted and weighed. Then seed samples of the same weight were planted into a peat-based potting mix[1] in 30 by 30 cm plastic flats, one species per flat, in four rows. Water was applied as needed. The weeds were grown in the greenhouse until flaming experiments were initiated.

Flamer Design. A covered flamer was designed to improve control of the flame and increase heat efficiency (Ascard 1997, 1999). The flamer shield was 2 m long by 35 cm wide by 20 cm high in the front and 10 cm high in the back. The shield was built from a 1.4 mm stainless steel sheet with no insulation. Two V-shaped liquid-phase burners[2] with a maximum capacity of 500,000 kJ (kilojoules) each were installed in the front of the cover directed backwards at an angle of 67 degrees. The flamer had a medium-capacity regulator[3] and a 12V DC solenoid valve[4] for security. A constant fuel pressure of 0.20 MPa was used and fuel consumption was estimated at 42.4 kg/h/m.

Plants were placed on a moving chain link conveyor that was driven by a 12V DC electric motor and controlled by a rheostat for infinite speed adjustment.

Weed Control Experiments. Studies consisted of four speed treatments at two developmental stages (0 to 2 and 2 to 4 leaves) and an untreated control. The treatment speeds of the moving belt were 2, 4, 6, and 8 km/h. All experiments were conducted twice.

Temperature inside the covered flamer was measured with a 4-channel type K thermometer.[5] The flamer generated temperatures inside the cover of 800 to 900 C in the first quarter of the cover where the burners were located, 600 to 800 C in the second quarter, 500 to 700 C in the third quarter, and 200 to 600 C in the fourth quarter. The amount of fuel consumption was kept constant.

Live plants were counted before treatment application and 14 d after treatment (DAT) to determine the number of weeds killed. Stands were very low compared to the number of seeds planted, but numbers were consistent within species. Leaf fresh weight was recorded 14 DAT. The experimental design was a randomized complete block with four replications. Data from each experiment were subjected to analysis of variance. Data from repeated experiments were pooled because there was no significant experiments by treatment interaction. Fisher's Protected LSD at $\alpha = 0.05$ significance level was used to detect differences among treatment means.

Results and Discussion

Grasses. Grass species and seedling size influenced effectiveness of flaming on plant death. Barnyardgrass at the 0- to 2-leaf stage flamed at 2, 4, and 6 km/h had stand counts similar to the untreated control 14 DAT. However, there was an increase in number of live plants compared to the untreated control at 8 km/h, and all treatments had more live seedlings at 14 DAT than on the day of flaming (Table 1). The

Table 2. The effect of flaming green foxtail seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage			2- to 4-leaf stage		
	Live plants		Fresh wt.	Live plants		Fresh wt.
	Initial	14 DAT	14 DAT	Initial	14 DAT	14 DAT
	no./flat		g/flat	no./flat		g/flat
2 km/h	103.0 a	0.2 b	0.02 b	61.3 a	13.8 d	3.21 b
4 km/h	99.8 a	4.5 b	0.15 b	57.3 a	24.3 cd	11.03 ab
6 km/h	90.5 a	7.8 b	0.45 b	61.3 a	31.8 bc	22.17 a
8 km/h	92.8 a	28.3 b	2.45 b	50.3 a	43.3 b	18.76 a
Untreated	95.8 a	129.7 a	71.04 a	55.3 a	65.0 a	24.23 a
LSD $_{(0.05)}$	NS	60.8	29.77	NS	17.1	14.68
CV	26.1	32.3	30.3	15.0	14.6	60.0

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

increased number of plants was a result of additional germination which might have been stimulated by heat produced during the treatment, as well as regrowth of some treated seedlings. Ascard (1995b) reported increased emergence of several weed species after flaming. He suggested that flaming might stimulate germination by breaking the dormancy of seeds lying near the soil surface. Even though the number of barnyardgrass plants at 14 DAT was similar to the untreated control for most treatments, fresh weight was significantly reduced for all application speeds compared to the untreated control. The fresh weight of flamed barnyardgrass at the 0- to 2-leaf stage was reduced by 84% or more at all speeds compared to the untreated control. There was no significant difference in barnyardgrass fresh weight between the flaming speeds. Thus, although flaming at the 0- to 2-leaf stage reduced barnyardgrass fresh weight, it did not reduce the number of live plants 14 DAT.

For barnyardgrass flamed at the 2- to 4-leaf stage, all treatments had more live plants 14 DAT than the initial stand. There was no significant difference in stand between treatments, including the control, with the exception of an increase in stand in the 6 km/h treatment. However, the fresh weight of the treated plants in all treatments was reduced by 80% or more compared to the untreated control. There was no significant difference in fresh weight among the treated plots, but there was a trend toward greater fresh weight as flaming speed increased. None of the flaming treatments resulted in total control of barnyardgrass. It is difficult to explain the increase in plant numbers after flaming at the 0- to 2-leaf stage. It is possible that at 8 km/hr there was sufficient heat to stimulate some seeds, but insufficient heat to kill all the emerged seedlings. At the slower speeds, seeds near the soil surface and seedlings just emerging might have been killed.

There were significant stand reductions in green foxtail 14 d after flaming at the 0- to 2-leaf stage (Table 2). Although there were no significant differences between flaming treatments, there was a trend toward better control with slower conveyor speed. At 2 km/h, the stand was reduced to 0 to 2 plants per flat, which was a reduction of almost 100% compared to the initial stand of 103 per flat. At 4 km/h, green foxtail stand was 4.5 plants per flat, or a reduction of 95%; at 6 km/h the stand was reduced 91%, and at 8 km/h the stand was reduced 70% compared to the initial stands. Green foxtail fresh weight 14 DAT was reduced 97% or more in all treatments compared to the untreated control. All flamer treatments had less than 1 g per flat fresh weight, except the 8 km/h treatment with 2.45 g per flat.

Stand counts 14 DAT of 2- to 4-leaf green foxtail were significantly lower than the untreated control, but reduction was not as great as at the 0- to 2-leaf stage (Table 2). At the 2- to 4-leaf stage, plants flamed at 2 km/h had 13.8 plants per flat, for a reduction of 77% from initial stand. At 4 km/h the reduction was 58%, at 6 km/h stands were reduced 48%, and plants flamed at 8 km had a stand reduction of 14%, compared to the original stand. However, only the flaming treatment at 2 km/h resulted in a significant reduction in

Table 3. The effect of flaming large crabgrass seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage			2- to 4-leaf stage		
	Live plants		Fresh wt.	Live plants		Fresh wt.
	Initial	14 DAT	14 DAT	Initial	14 DAT	14 DAT
	no./flat		g/flat	no./flat		g/flat
2 km/h	35.5 a	18.0 c	6.33 d	34.3 a	23.3 b	9.89 b
4 km/h	31.8 a	24.5 bc	15.17 cd	39.3 a	41.5 a	16.10 ab
6 km/h	42.0 a	44.0 a	36.75 b	43.0 a	44.0 a	26.62 a
8 km/h	36.8 a	38.5 ab	23.65 bc	40.5 a	34.0 ab	19.79 ab
Untreated	33.5 a	37.0 ab	58.32 a	43.5 a	41.8 a	21.01 ab
LSD $_{(0.05)}$	NS	18.1	16.12	NS	15.4	15.43
CV	31.6	36.2	37.3	15.4	26.4	32.4

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

Table 4. The effect of flaming redroot pigweed seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage			2- to 4-leaf stage		
	Live plants		Fresh wt.	Live plants		Fresh wt.
	Initial	14 DAT	14 DAT	Initial	14 DAT	14 DAT
	no./flat		g/flat	no./flat		g/flat
2 km/h	63.3 a	2.0 b	0.17 b	74.00 a	1.63 b	0.14 b
4 km/h	63.8 a	4.0 b	0.65 b	70.00 a	2.75 b	0.35 b
6 km/h	65.8 a	2.3 b	0.21 b	70.13 a	3.75 b	0.76 b
8 km/h	55.3 a	10.8 b	2.58 b	69.38 a	6.00 b	3.06 b
Untreated	61.0 a	66.8 a	66.17 a	69.38 a	65.75 a	46.07 a
LSD $_{(0.05)}$	NS	13.4	9.25	NS	8.3	7.07
CV	19.7	37.6	23.0	18.4	31.8	38.5

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

fresh weight compared to the untreated control. The other treatments were not statistically different from the untreated control, but there was a trend of increasing fresh weight of surviving plants with faster flaming speeds.

In green foxtail with 2 to 4 leaves, fresh weight reduction was 87% at 2 km/h, 55% at 4 km/h, 9% at 6 km/h, and 23% at 8 km/h, compared to initial stands. Flaming of green foxtail was obviously much more effective at the 0- to 2-leaf stage. At the 2- to 4-leaf stage, the only flaming speed that reduced stand and fresh weight significantly was 2 km/h.

Large crabgrass was more resistant to flame weeding than barnyardgrass and green foxtail. Significant stand reduction after flaming at the 0- to 2-leaf stage was achieved only at 2 km/h, with a 49% stand reduction, compared to the initial stand (Table 3). At 4 km/h stand reduction was 23% compared to the initial stand, but the final stand was not statistically different from the untreated control. Treatments at 6 and 8 km/h had no reduction in stand 14 DAT. However, large crabgrass fresh weight 14 DAT was significantly reduced by all treatments compared to the untreated control. Fresh weight reduction was 89% at 2 km/h, 74% at 4 km/h, 37% at 6 km/h, and 59% at 8 km/h, compared to the untreated control. The greater fresh weight at 6 km/h than at 8 km/h probably was a result of a larger number of emerged large crabgrass plants at the time of flaming in the 6 km/h flats compared to the 8 km/h flats. Flame weeding of large crabgrass at 0 to 2 leaves was not sufficiently effective at any application speed. Marginal control was achieved at 2 km/h. Although fresh weight was reduced in all speed treatments, a large number of crabgrass plants survived.

When large crabgrass was flamed at the 2- to 4-leaf stage, only the 2 km/h treatment reduced stands 14 DAT compared to the untreated control (Table 3). There was no significant reduction in fresh weight for any of the treatments compared to the untreated control; however, there was a decrease in fresh weight of 53% for flaming at 2 km/h. Flaming was ineffective at any speed for control of 2- to 4-leaf large crabgrass.

Broadleaves. Previous research has demonstrated that flaming is more effective against broadleaf weeds than grasses (Ascard 1994, 1995a). The broadleaf weeds treated in these experiments were controlled by flaming at all treatment speeds and at all growth stages.

Flaming of redroot pigweed at the 0- to 2-leaf stage was very effective at 2, 4, and 6 km/h, with stand reductions of 97, 94, and 96% respectively, compared to the initial stands. At 8 km/h redroot pigweed stand count was reduced 84% from the initial stand (Table 4). Fresh weight was greatly reduced by all flaming treatments. At speeds of 2, 4, and 6 km/h, fresh weights were reduced 99% or more and at 8 km/h the reduction was 96% compared to the untreated control. Flaming was slightly less effective at the 2- to 4-leaf stage. All treatments had at least 91% reduction in stand compared to the initial stands and 93% reduction in fresh weight, compared to the untreated control.

Table 5. The effect of flaming common ragweed seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage			2- to 4-leaf stage		
	Live plants		Fresh wt.	Live plants		Fresh wt.
	Initial	14 DAT	14 DAT	Initial	14 DAT	14 DAT
	no./flat		g/flat	no./flat		g/flat
2 km/h	29.5 a	5.5 b	0.52 b	26.1 ab	0.9 b	0.08 b
4 km/h	30.3 a	5.1 b	0.39 b	22.0 b	0.9 b	0.05 b
6 km/h	33.0 a	5.3 b	0.46 b	29.3 a	2.8 b	0.37 b
8 km/h	33.3 a	6.5 b	0.61 b	25.5 ab	3.0 b	0.30 b
Untreated	29.8 a	29.1 a	17.27 a	25.0 ab	25.9 a	13.55 a
LSD $_{(0.05)}$	NS	3.3	4.28	4.4	6.6	1.90
CV	18.1	18.8	18.7	17.0	41.8	34.7

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

Table 6. The effect of flaming common lambsquarters seedlings at the 0- to 2- and 2- to 4-leaf stages (means[a] from two pooled experiments).

Speed	0- to 2-leaf stage			2- to 4-leaf stage		
	Live plants		Fresh wt.	Live plants		Fresh wt.
	Initial	14 DAT	14 DAT	Initial	14 DAT	14 DAT
	no./flat		g/flat	no./flat		g/flat
2 km/h	101.4 a	1.3 b	0.02 b	76.3 ab	1.0 b	0.06 b
4 km/h	103.4 a	1.4 b	0.10 b	72.5 b	0.3 b	0.01 b
6 km/h	98.1 a	3.5 b	0.12 b	86.0 ab	0.4 b	0.03 b
8 km/h	94.8 a	4.4 b	0.13 b	107.0 a	0.3 b	0.01 b
Untreated	103.8 a	31.5 a	11.56 a	86.0 ab	80.8 a	26.18 a
$LSD_{(0.05)}$	NS	3.3	1.93	32.9	6.5	1.52
CV	12.5	38.6	39.0	24.9	13.0	7.0

[a] Values within a column followed by the same letter in a column are not statistically different at P = 0.05, NS = Not significant at P = 0.05.

Common ragweed appeared to be slightly tolerant to flaming at the 0- to 2-leaf stage. Stands were reduced 81, 83, 84, and 80% from initial stands for 2, 4, 6, and 8 km/hr treatment speeds, respectively. Fresh weight was reduced 97, 98, 97, and 96% of control by 2, 4, 6, and 8 km/hr, respectively (Table 5). However, the fresh weight was less than 1 g for all treatments and 17.27 for the untreated control. Because the number of plants in the control flat did not increase during the 14 d between treatment and evaluation, it appears that there was little or no new germination. Thus, the live plants probably regrew from the roots of the flamed plants.

There were very few live common ragweed plants 14 DAT flamed at the 2- to 4-leaf stage. Approximately three plants survived per flat in the 6 and 8 km/h treatments, and approximately one plant per flat survived the 2 and 4 km/h treatments. This was equivalent to a 97, 96, 90, and 88% reduction in stand from initial stand and 99, 99, 97, and 98% reduction in fresh weight compared to the untreated control. Fresh weight of all treatments was less than 1 g per flat, compared to 13.5 g for the untreated control. Obviously, common ragweed was more susceptible to flaming at the 2- to 4-leaf stage than at the 0- to 2-leaf stage.

The response of common lambsquarters to flaming was similar to that of common ragweed. Flaming at the 2- to 4-leaf stage was more effective than flaming at the 0- to 2-leaf stage. Common lambsquarters control was 86% or higher when flamed at the 0- to 2-leaf stage, and 99% or higher when flamed at the 2- to 4-leaf stage (Table 6). These results were similar to results reported by Ascard (1995b). Most likely, a few plants were emerging at the 0- to 2-leaf stage which were not killed by the flame. At the 2- to 4-leaf stage, the plants were larger with more surface area making them more susceptible to the flame.

Our results indicate that these broadleaf species were susceptible to flaming at both growth stages. Slight differences in susceptibility between 0- to 2- and 2- to 4-leaf stages may be related to uniformity of germination or location of the growing point below the soil surface. Ascard (1995a, 1998), Diver (2002), and Mojžiš (2002) reported that broadleaves at later growth stages were more resistant to heat than seedlings at earlier stages. Older plants have larger surface area and greater biomass, which requires a higher flaming dose to heat and destroy. Ascard (1994) found a linear relationship between weed fresh weight and the effective propane dose for 95% weed reduction. The results of this study appear to be inconsistent with Ascard's results; however, earlier plant growth stages were used in this study than those used by Ascard, and his research was conducted in the field.

Grass seedlings are difficult to kill with flaming because their growing point is usually below the soil surface at time of treatment. Ascard (1995a), Diver (2002), and Mojžiš (2002) also reported that grasses were more heat resistant than broadleaves because the grass sheath protects the growing point. Flaming of very young seedlings might be more effective if it is repeated. More research needs to be done with repeated flaming to young seedlings of several grass species to determine an effective method of using the technology for weed control in the field.

Sources of Materials

[1] Baccto professional planting mix, Michigan Peat Company, Houston, TX 77098-0129.

[2] Liquid phase burners, Model LT 1½ × 8 D Liquid Torch, Flame Engineering, Inc., P.O. Box 577, LaCrosse, KS 67548.

[3] Regulator, Model 567, Flame Engineering, Inc., P.O. Box 577, LaCrosse, KS 67548.

[4] Solenoid, Valve Model S122, Flame Engineering, Inc., LaCrosse, KS 67548

[5] K thermometer, Omega Model HH501DK, Omega Engineering, Inc., Stamford, CT 06907-0047.

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