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Feasibility of solar tents for inactivating weedy plant propagative material

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Abstract Solar tents, which are safe, inexpensive, and easy to construct, can be used to inactivate unwanted weed plant propagative materials, onsite. During two field trials in the San Joaquin Valley of California, from Sept 2 to 7, 2010, solar tents produced diurnal temperature maxima within closed sample bags of 63.5–76.7°C. The mean maximum temperatures within the sample bags were 32.9–42.1°C higher than those of ambient air, and temperatures ≥60°C were maintained for 3.2–6.0 h each afternoon during the field trials. Rhizome segments, excavated and excised from a local infestation of the important weed pest *Sorghum halepense* (johnsongrass), were used to evaluate effects of the treatment on weedy plant tissues with vegetative propagation capability. The rhizomes were completely destroyed following confinement within tents for 3 days. Construction suggestions for building onsite solar tents are presented, with emphasis on use of locally available materials. In sufficiently warm climatic areas and weather conditions, solar tents can provide a useful alternative for inactivating weed propagative materials. Potential uses include destruction of quarantined, propagative materials following regulatory roguing interventions in remote locations, or routine roguing of limited scale areas to remove invasive weeds.

Keywords Appropriate technology · Ecological restoration · Solar energy · Solarization · Weeds · Wildland

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Introduction

Passive solar heating of moist soil beneath clear plastic film is used as a non-chemical alternative to soil fumigation in cultivated agriculture (Stapleton 2000). In addition, it has shown promise for use in wildland and other ecological restoration efforts (Bainbridge 1990; Moyes et al. 2005; Stapleton and Jett 2006; Marushia and Allen 2011). Weed seed inactivation is one of the most beneficial results obtained from heating soil. A factor limiting effectiveness of soil heating in open fields is "top-down" efficacy resulting from the solar energy source overhead. This gives maximal pesticidal efficacy in uppermost soil layers, which decreases with increasing soil depth (Rubin and Benjamin 1984).

Aboveground solar tenting, as opposed to open-field treatment, was developed as a method for eradicating soil pests in smaller volumes of soil, such as used in horticultural container nurseries (Stapleton et al. 2002). The concept was based on the demonstration of increased soil heating using two, rather than one layer of plastic film (Ben-Yephet et al. 1987). Early results with solar tents showed that optimal heating occurred when containers of soil were elevated off the soil surface, to allow for heating on all sides of the targeted soil masses. Using the solar tent method, container-sized soil volumes can be routinely heated in warm climates to ≥70°C, similar to temperatures employed during soil disinfestation with aerated steam. Since, most mesophilic organisms can tolerate only short periods of exposure to these temperatures when hydrated, soil in solar tents can often be disinfested of weeds, nematodes, and pathogens over the course of one warm afternoon (Stapleton et al. 2002). The California Department of Food and Agriculture (2004) approved a solar tent treatment method for regulatory prevention of nematode pests in commercial nursery soil and planting media.

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A further adaptation of the solar tent concept was tested to inactivate dormant, aerial seeds of skeleton weed plants which were rogued in remote, wildland areas (Stapleton et al. 2008). This was desirable because herbicide application to dormant seed protective structures, such as desiccated thistle capitulae, would not be effective and employment of other sanitation methods, such as incineration, deep burial, or physical removal was not possible. This report describes and discusses the feasibility, construction, and use of solar tents for on-site inactivation of aerial, plant propagative material.

Materials and methods

The two validation trials described herein were conducted in an open, agricultural field area near Oakdale, California (lat 37°79′N, long 120°86′W; elevation 48 m), in the northern San Joaquin Valley. The treatment dates of the two experiments were Sept 2–4 and 5–7, 2010.

Solar tent construction

Three, replicate, solar tents were constructed, mostly from materials simulating those that might commonly be found by scavenging in a chaparral or Sierra Nevada foothills ecoregion in California. The tents were constructed with attention to experimental uniformity. For each replicate, a 2 × 2 m square of black, polyethylene, painters' tarping, 0.1 mm (4 mil) thick, was placed directly on the soil surface. Four pieces of concrete rubble, ca. 15 × 15 × 15 cm to simulate rocks, were placed at the corners of a 1 × 1 m square at the center of the subtending black film square, and 2.5-cm diameter × 1-m-long shoots of a nearby mulberry (*Morus* spp.) tree were placed on the rocks, creating an elevated, lattice framework on which to support the sample-containing bags, 10 cm above the tarped soil surface (Fig. 1). Thinner shoots, 1 cm-diameter × 1.5-m-long, were bent into hoops, placed over the framework, and secured with cotton twine to support the tent canopy, which consisted of a sheet of clear, 4 mil thick, polyethylene painters' tarping. The tarping was anchored and sealed using additional pieces of concrete rubble, taking care to minimize the potential for heated air to escape from within the tents. Approximately 20–30 cm of air space existed between the top of the sample bags and the tent canopy.

Rhizomes

Freshly excavated, visually healthy rhizomes of *Sorghum halepense* (johnsongrass), an important weed pest which was available and collected at the field site, were rinsed free of soil in tap water, cut with hand pruners into ca. 10-cm-long segments (each possessing at least two nodes) and placed into ca. 30 × 30 cm organdy fabric squares. The edges of the fabric with enclosed rhizomes were gathered together and tied tightly with cotton twine. One sample bag for each replication of solar tent treatment was then inserted into a black polyethylene, 113-l-capacity, outdoor trash bag, containing 500 ml tap water to hydrate the atmosphere within the bags. Sample bags were suspended from the open tops of the black trash bags, which were then tightly secured with twist-ties, by the long ends of the cotton twine, sample bag closures, to prevent the samples from directly contacting the water reservoirs within the trash bags. External thermocouples were placed alongside the organdy sample bags within each black trash bag, and secured in place with the twist-ties. Thermocouples were attached to Hobo microloggers (Onset Computer Corp., Bourne, MA, USA) for continuous temperature monitoring during experiments. Untreated, control rhizome cohorts were placed on moist paper towels within clear plastic vegetable storage boxes and maintained under ambient, indoor conditions (ca. 30°C diurnal max; 21°C min; 12 h daylight).

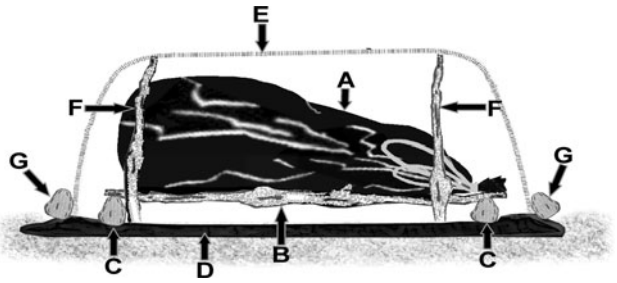

Fig. 1 Diagram of solar tent construction used in this study: *a* closed, black plastic bag, e.g., 151 l (40 gal) volume, containing targeted plant material and 0.5–1.0 l water for free moisture presence, *b* interior framework of woody plant shoots, sitting on *c* rocks, to elevate bag above soil surface and allow heat to surround target, *d* sheet of black plastic film on soil surface to assist with heat accumulation and preclude escape of propagative material onto the soil, *e* clear plastic sheet, supported by *f* hoops of woody plant shoots to form a tent over the treatment bag, *g* exterior rocks, soil and/or logs sealing edges of tent canopy to minimize heat loss and preclude escape of propagative material

Rhizome sprouting data

Rhizome sample bags were treated within the solar tents for 72 h (three diurnal heating cycles). When removed from tents, sample bags were opened indoors and rhizome segments were visually examined for sprouting. They were then loaded into covered, clear plastic vegetable storage containers containing moistened paper toweling and both treated and control rhizome sample containers were placed into an incubator (Model 146E, Fisher Scientific Co., Dubuque, IA, USA), set for 16 h of operation each day at

30°C with exposure to a fluorescent grow light. During the daily 8 h of nonoperation, incubator temperature dropped to indoor ambient temperature (ca. 21–23°C), in darkness. During the 30-day-incubation period, deionized water was added to the containers as needed to maintain adequate moisture. Rhizomes were checked for sprouting and the presence of moisture every 1–3 days, and sprouted rhizomes were not removed and discarded until the end of the 30-day-incubation period.

Results

Solar tent temperature data

During the two field trials conducted in this study, solar tents produced diurnal temperature maxima within enclosed sample inactivation bags of 63.5–76.7°C (Fig. 2). Mean maximum temperatures within the closed sample bags ranged from 32.9 to 42.1°C higher than those of outdoor ambient air, measured 1.5 m above the soil surface in open sunlight (Fig. 3) at a local weather station, ca. 8.8 km from the experimental site (California Department of Water Resources 2011). Within-bag temperatures ≥60°C persisted for 3.2–6.0 h, each afternoon of the experimental period.

Rhizome sprouting

None (0%) of the rhizome segments treated for 3 days in solar tents sprouted after 30 days incubation (Table 1) following the two experiments with *S. halepense*. Rhizomes in Experiment #1 were exposed to a mean of 16.2 h at or above 60°C, while those in Experiment #2 were exposed to 10.0 h above 60°C. On the other hand, all (100%) of the nontreated control rhizome segments of *S. halepense* sprouted following the 30-day-incubation period following treatment. The nonsprouted, heat-treated rhizome segments were completely colonized by decay microorganisms by the end of the 30-day-incubation period (Fig. 4). The results of the two experiments with rhizome segments constituted "perfect" datasets (all sprouted vs. none sprouted; no variance); hence, statistical analysis was not appropriate.

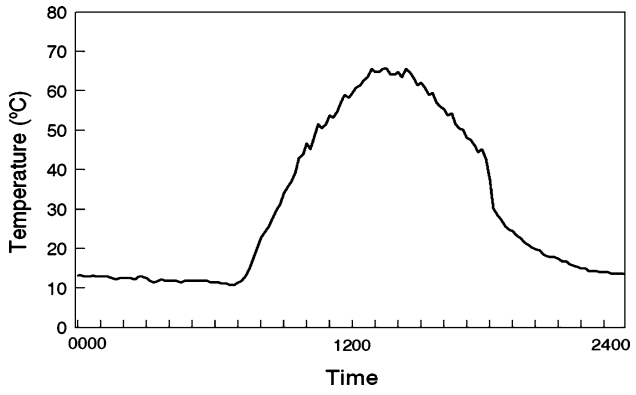

Fig. 2 Typical diurnal heating curve within closed black plastic bag inside clear film tent ("double tent"). Reference ambient air maximum = 34.1°C (taken from nearby CIMIS weather station, Oakdale, San Joaquin Valley, Station #194). Sept 3, 2010, Oakdale, CA

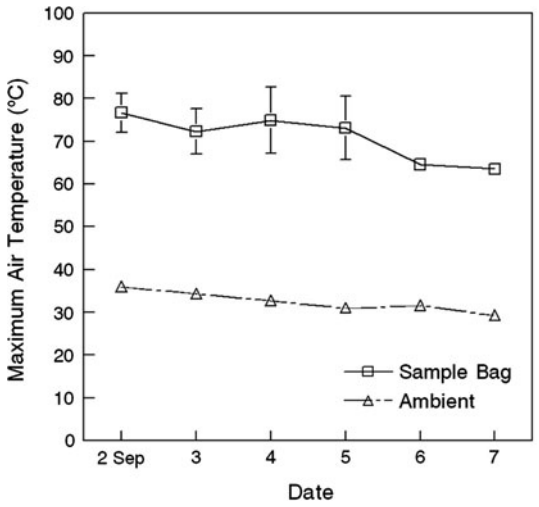

Fig. 3 Maximum air temperatures during solar tent experiments, Sept 2–7, 2010, near Oakdale, CA. Sample bag interior temperatures are means of two (Sept 4–7) or three (Sept 2–3) replications (±1 SEM). Reference air temperatures are taken from nearby (ca. 8.8 km) CIMIS weather station (Oakdale, San Joaquin Valley, Station #194)

Table 1 Effect of solar tent exposure on sprouting of *S. halepense* (johnsongrass) rhizome segments, Oakdale, CA, USA, 2010

Experiment	Heating dates	Rhizome segment sprouting	
		Mean number sprouted per 10 segment	
		Replication[a]	
		Nontreated control	Solar tented
#1	2–4 Sept[a]	10/10	0/10
#2	5–7 Sept[b]	10/10	0/10

Rhizome segments were placed within organdy fabric bags for treatment

[a] Tented exposure for 3 days; mean 16.2 h total ≥60°C

[b] Tented exposure for 3 days; mean 10.0 h total ≥60°C

Discussion

These field validation trials confirmed that solar tents, an adaptation of the "double tent" soil heating technique (Stapleton et al. 2002), provided air temperatures sufficient to completely inactivate hydrated *S. halepense* rhizome segments after a 3-day exposure under moderate, late summer

Fig. 4 Representative comparison of *S. halepense* rhizome segments after 30-day-post-tenting incubation, showing killed, solar-tented segments (*bottom row*) and sprouted, nontreated control segments (*top row*)

weather conditions in California. It must be strongly emphasized that earlier field and laboratory work (Stapleton et al. 2008, 2009) has pointed out the critical requirement for free moisture within the closed sample bags, to imbibe or hydrate target materials and obtain highest lethal efficacy.

Thermal inactivation studies under controlled conditions have been previously conducted on seeds of many important, weedy plant taxa, such as *Xanthium strumarium* (rough cocklebur), *Abutilon theophrasti* (velvetleaf), and *S. halepense* (Egley 1990), *Avena sterilis* (animated oat), *Bromus diandrus* (ripgut brome), and *Sinapis arvensis* (charlock mustard) (Economou et al. 1998), and *Sisymbrium irio* (London rocket) and *Amaranthus albus* (tumble pigweed) (Dahlquist et al. 2007). These previous studies demonstrated that, at higher temperatures of 60–70+°C, hydrated seeds of most taxa can be rapidly inactivated, under conditions similar to those encountered during this study. The results presented here with *S. halepense* rhizome segments indicated that vegetative plant material, as well as seeds, may be readily inactivated in solar tents, under conducive environmental conditions.

The solar tent construction technique described in this report should be considered as merely a prototypic suggestion. The methodology described was intended to provide a basis for further "appropriate technology" engineering that could be adapted for the widest possible array of locations and end user resources. Employment of locally scavenged components for tent construction limited required purchases to plastic sheeting and target material collection bags. However, many restoration situations and sites (e.g., parks, nature preserves, watercourse drainages, etc.) would allow for onsite delivery of construction materials, eliminating the need for scavenging. Also, semi-permanent designs could be constructed in the same manner as are agricultural plastic houses or high tunnels. Solar tent scale is equally as flexible, by means of simply altering the tent dimensions to construct larger tents. A set of images describing additional details of solar tent construction has been published, and is available by accessing the referenced web link (Stapleton 2009).

Under suitable climatic and weather conditions, solar tents can have a myriad of uses in pest management, including applications in ecological restoration. Here, they were shown to be of value for on-site eradication of weed propagative tissues. At the high temperatures reached, and with sufficient hydration, complete inactivation should be possible for propagative material of most plant taxa. Employment of solar tents could be useful to help eradicate weedy plant infestations discovered in remote areas or in other locations where manual or mechanical roguing and transport of plants with viable seeds or propagative tissues might result in unintended weed dispersal. Caution should be used to assure that sufficient heat dosage for complete inactivation has been accumulated, before releasing treated weed propagative material into the environment.

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