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Burning Nettle (*Urtica urens*) Germination and Seedbank Characteristics in Coastal California

Ran N. Lati, Shachar Shem-Tov, and Steven A. Fennimore*

Burning nettle is a noxious weed that commonly infests coastal California vegetable fields. Weed control programs for lettuce and fresh spinach grown in this area do not adequately control burning nettle, and escaped weeds that mature are highly problematic during hand weeding and harvesting. Information on the biology and ecology of burning nettle is limited, and work was conducted to develop information about this weed. The objectives of this study were to evaluate the effect of temperature on burning nettle germination and to determine its base temperature value, to characterize the germination pattern of this weed and seedbanks under local California coastal conditions, and to estimate the optimal timing for burning nettle removal by herbicides and physical methods. The upper optimal temperature for burning nettle germination was 22.8 C, but there was no difference in the final germination percentage between 4 and 22.8 C. The base temperature was determined to be 3 ± 0.2 C, and this information allowed the development of temperature-based optimal control timing models. In the field, burning nettle emerged throughout the year without any seasonal pattern, and germinable seeds were also found in the seedbank throughout the year. Burning nettle was able to complete a growth cycle throughout the year in coastal California. Burning nettle has a short growth cycle that allows it to set viable seeds within 466 ± 13 growing degree days (GDD), and this timing is critical for burning nettle removal by herbicides, cultivation, or hand weeding. The optimal timing for phenmedipham application at 180 g ai ha^{-1} was estimated to be 205 GDD. The germination and seedbank field studies indicate why burning nettle is so well adapted to the mild climate of coastal California. However, results presented here suggest strategies to reduce the burning nettle seedbank, improve its control, and allow more efficient lettuce and fresh spinach production.

Nomenclature: Phenmedipham; burning nettle, *Urtica urens* L., lettuce, *Lactuca sativa* L. var., spinach, *Spinacia oleracea* L. # SPQOL.

Key words: Burning nettle germination, burning nettle seedbank, fresh market spinach, growing degree days, lettuce, phenmedipham, temperature.

The Salinas Valley on the Central Coast of California has mild temperatures all year with low seasonal fluctuations compared with continental climates (CIMIS 2015). This unique climate allows production of vegetable crops such as lettuce and fresh market spinach most of the year, mainly between March and September, and is the reason these areas are important vegetable production regions (Samtani et al. 2014). The same moderate conditions and the long vegetable growing season allows a range of cool- and warm-season weeds like shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.], common purslane (*Portulaca oleracea* L.), common groundsel (*Senecio vulgaris* L.), and annual bluegrass (*Poa annua* L.) to pose a significant economic risk for vegetable production (Odero and Wright 2013; Samtani et al. 2014; Shem-Tov and Fennimore 2003). Vegetables are generally weak competitors, and weeds must be controlled to maintain produce quantity and quality standards (Fennimore et al. 2014). Weed control systems of most vegetable crops integrate several weeding tactics that includes herbicides, cultivation, and hand weeding for optimal results (Fennimore and Doohan 2008).

Burning nettle is a cool-season annual that infests vegetable fields in coastal California (Samtani et al. 2014). PRE herbicides used for fresh spinach and lettuce, such as cycloate and bensulide, respectively, do not provide adequate control of burning nettle, and there are no available POST broadleaf herbicides for these crops (Anonymous 2015a; Daugovish et al. 2007; Lati et al. 2015). Fresh spinach is planted at high densities (32-48 seed lines per 2-m-wide bed), which makes mechanical cultivation between spinach rows impossible (Fennimore et al. 2014). Hand weeding is necessary to achieve commercially acceptable weed control and is

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* Postdoctoral Researcher, Postdoctoral Researcher, and Extension Specialist, University of California, Davis, Department of Plant Sciences, 1636 East Alisal, Salinas, CA 93905. Corresponding author's E-mail: ranlati@gmail.com

a key component in vegetable weed control systems (Slaughter et al. 2008). This weeding tactic is usually carried out before harvest, when weeds are already large (Takele 2013). Because burning nettle has stinging hairs on the plant surfaces, manual weeding and harvesting of infested lettuce and spinach fields is very unpleasant (Smith et al. 2011). Burning nettle is also a serious problem for machine-harvested vegetables like baby spinach and baby leaf lettuce because produce shippers have no tolerance for leafy vegetables contaminated with burning nettle (Smith et al. 2013).

Integrated weed management systems require greater information about the biology and phenology of weeds under local environmental conditions. Such data can be used to predict weed infestation risk through time, thus facilitating decisions about field selection and optimal timing of weeding activities (Ghersa et al. 2000). Biological, physiological, and agronomical information about burning nettle is very limited. Buhler and Hoffman (1999) evaluated the germination of burning nettle under controlled conditions. Boot et al. (1986) compared the flowering physiology of burning nettle and stinging nettle (*Urtica dioica* L.) under drought conditions, and Fitter et al. (1995) estimated the time to first flower. However, the Buhler and Hoffman (1999) study was not validated under field conditions, where environmental conditions would vary. Boot et al. (1986) and Fitter et al. (1995) focused only on the flowering stage but did not refer to the seed production stage, which is of greater interest in terms of weed control and can support development of more effective and sustainable control systems for this weed. Roberts and Feast (1973) mentioned the importance of cultivation to reduce the burning nettle seedbank but did not provide a means for decision making regarding its removal. There is a need for basic burning nettle biological data, such as base temperature (T_b) value; annual emergence patterns; and phenological data, such as time to set viable seed. Lati et al. (2015) recently demonstrated the potential for use of phenmedipham as a POST herbicide for fresh spinach, an herbicide that is highly efficacious on burning nettle. Nonetheless, these authors did not determine the optimal phenmedipham application timing for burning nettle. Therefore, the objectives of this study were to (1) evaluate the effect of temperature on burning nettle germination and determine its base temperature value, (2) characterize the burning nettle seedbank and germination patterns under California Central Coast conditions, and (3) estimate the optimal burning nettle removal and phenmedipham application timings.

Material and Methods

Burning nettle seeds were collected at full maturity from local populations of infested fields near Salinas, CA (36.67°N, −121.60°W), during 1999 to 2014. Seeds were air-dried for 2 mo in a greenhouse, cleaned, then stored at room temperature (approximately 18 C) in dark, dry conditions until use.

Germination Test. This study was conducted in the lab using growth chambers at constant temperatures in darkness as recommended by Buhler and Hoffman (1999). Seeds were placed on filter paper (Whatman no. 3, Fisher Scientific, Park Lane, Pittsburgh, PA 15275), moistened with 5 ml of deionized water in 90-mm-diam petri dishes sealed with Parafilm, and incubated at 4, 7, 10, 13, 16, 19, 22, and 25 C. During observations, the petri dishes were watered as need to maintain optimal moisture. Each temperature treatment consisted of four replicates with 100 seeds per petri dish. The criterion for germination was a visible radicle > 1 mm long. The germinated seeds were counted and removed daily until no more germination occurred for at least 10 d. Temperature of each growth chamber was recorded throughout the study using temperature sensors (HOBO TMC6-HD) linked to data loggers (U12-008, Onset HOBO, Pocasset, MA 02532). Mean temperature values were used for the statistical analysis.

Statistical Analysis. Analysis for the germination study was conducted using SAS (SAS, version 9.3, SAS Institute Inc., Cary, NC 27513). Experiments were conducted twice. There were no experiment by treatment interactions; therefore, data were pooled. The final germination rate (%) was transformed to arcsine values using the ARSIN function and subjected to ANOVA (Tukey–Kramer Honestly Significant Difference test $P = 0.05$). One-way ANOVA was conducted using PROC GLM to determine the effect of temperature on burning nettle final germination percentage. Data was back-transformed for presentation. The final germination percentage was also plotted against temperatures using trapezoid pattern regression by PROC NLIN. This model estimates base and ceiling temperatures, below and above which germination will be zero, respectively, and the lower and upper optimum temperatures. Because our data did not include

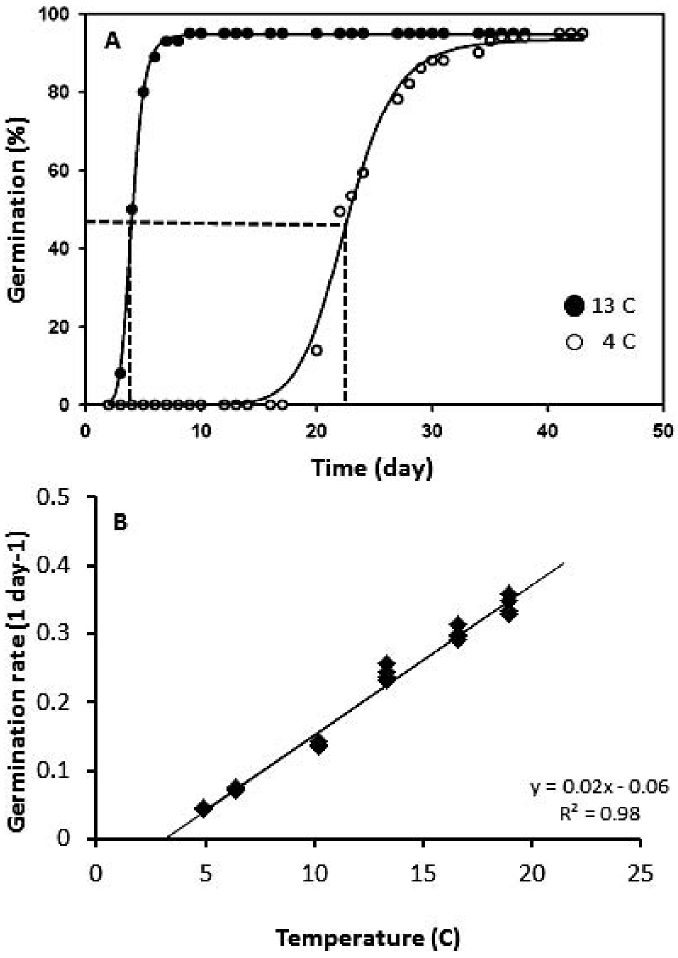

Figure 1. Example of the base temperature (T_b) evaluation method. (A) The effect of temperature on observed (symbols) and fitted (lines) burning nettle germination at 4 and 13 C. Dashed lines demonstrate the differences in days to 50% final germination (d_{50}) values of these incubation temperatures, despite their similar final germination rates. (B) The effect of temperature on burning nettle germination rate (GR). Symbols are observations, and the line is the fitted linear regression. GR was calculated as the inverse of d_{50}. The evaluated burning nettle T_b was 3.0 C.

suboptimal temperatures, a simpler trapezoid version that included upper optimum and ceiling temperatures was used. Then, for each replicate, the germination rate (GR) was calculated as the inverse of d_{50}, which is the time necessary for half of the seeds to germinate (Figure 1A). The d_{50} parameter was evaluated via a three-parameter nonlinear log-logistic equation:

$$y = m/1 + (x/d_{50})^b \qquad [1]$$

where y is burning nettle germination percentage, m represents the upper asymptote (maximum germination percent), x represents time (days) from the study initiation, and b represents the slope at d_{50}. Analysis was performed using PROC NLIN.

Figure 1B demonstrates the T_b evaluation, which requires a linear regression between GR values and their corresponding temperatures. Data from temperatures outside the linear range effect of temperature extremes were not included in the analysis (Trudgill et al. 2005). GR values of all replicates of relevant treatments were linearly regressed against their corresponding incubation temperatures with a_t and b_t as the intercept and slope parameters, respectively. T_b was set as the intercept of the regression line with the temperature (x axis) when GR is equal to zero. T_b standard error (SE) was then evaluated as proposed by Greene (2003)

$$\mathrm{SE} = \sqrt{\frac{V(a_t)}{b^2} - \frac{2 \times a \times v(a_t b_t)}{b^3} + \frac{a^2 \times V(b_t)}{b^4}} \qquad [2]$$

where $V(a_t)$, $V(b_t)$, and $V(a_t b_t)$ are the variances of a_t and b_t and the covariance associated with a_t and b_t. Variance and covariance values were extracted using OUTEST COVOUT.

Dose Response. To evaluate burning nettle response to phenmedipham rates at a range of growth stages, a dose–response assay was performed. Pots (8-cm diam) were filled with soil and seeded with burning nettle. Plants were grown outside the greenhouse under direct sun conditions. At 10, 20, and 30 d after seeding (DAS), pots were treated with phenmedipham (Spin-Aid, Engage Agro, Phoenix, AZ 86303) at 0, 18, 45, 137, 410, 900, 1,800, and 3,600 g ha^{-1} using a CO$_2$-pressurized backpack sprayer equipped with 8002VS flat fan nozzles (Tee Jet Technologies, Wheaton, IL 60189) calibrated to deliver 337 L ha^{-1} at 290 kPa. After spraying, plants were left outside the greenhouse. Ten days after treatment, the aboveground parts of the plants were harvested and dried at 80 C for 6 d, and dry weights were recorded. Experiments were conducted in May and repeated in August 2014. Average temperatures were 15.5 and 17.6 C, and average light conditions were 294 and 232 W m^{-2} for the May and August experiments, respectively.

Statistical Analysis. Experiments were conducted with five replicates for each rate (40 pots per experiment). There were no experiment by treatment interactions; therefore, data were pooled. Dry weight data were analyzed against phenmedipham rate using Equation 1. Here, y is burning nettle dry weight (percent control), m is the upper asymptote (maximum burning nettle dry weight), x is phenmedipham rate (g ha^{-1}), d_{50} is the rate when

Table 1. Day length interval and day/night temperature settings in the growth chamber experiments.

Experiment timing	Growth chamber setting		
	Day length	Day	Night
	h	——C——	
Spring I: March 21 to May 5	11.5	25	3
Spring II: May 6 to June 20	14.0	25	9
Summer I: June 21 to August 5	14.0	25	14
Summer II: August 6 to September 20	13.5	28	14
Fall I: September 21 to November 5	11.5	25	6
Fall II: November 6 to December 20	10.0	20	5
Winter I: December 21 to February 3	10.0	20	−1
Winter II: February 4 to March 20	9.5	20	2

y is 50% of maximum (ED_{50}), and b is the slope at d_{50}. The phenmedipham rate that provided 90% burning nettle control (ED_{90}) was estimated as proposed by Motulsky and Christopoulos (2004):

$$ED_z = ED_{50} \times (z/100 - z)^{1/b} \qquad [3]$$

where $z = 90$ and can be adjusted as needed. The relationship between ED_{90} and time (GDD) was analyzed using PROC REG.

Field Emergence and Seedbank Study. The study was conducted during 1998 and 2001 at the Hartnell field station near Salinas, CA (36.67°N, −121.60°W). Soil type was a Chualar loam, fine-loamy, mixed, thermic Typic Argixeroll (79% sand, 14% silt, and 7% clay) with pH 7.2 and 1% organic matter content. Weed emergence was determined every 45 d and before weed removal activities such as cultivation, hand weeding, or tillage. Plots were divided into four 25-m^2 subplots. Fields were managed using cultural practices typical of the Salinas Valley (Ryder 1999), including crop rotation, deep tillage, fertilizer application, use of 1-m raised beds, and sprinkler irrigation. Field history and crop rotation has been described by Shem-Tov and Fennimore (2003). The only exception to this practice was that herbicides were not used, to allow an unrestricted assessment of the weed germination dynamics.

Field Emergence. Five 0.09-m^2 quadrats were established randomly in a W-shaped pattern within each subplot (Forcella et al. 1992). After establishment, quadrat locations were mapped and maintained fixed throughout the study. In each evaluation, emerged burning nettle seedlings were identified, counted, and removed from the quadrats. The number of emerged seedlings for each subplot was averaged over the five quadrats.

Seedbank. Twenty soil samples (5 cm wide by 7 cm deep) were collected from each subplot. Soil samples were pooled and potted in 676-cm^2 by 5-cm-deep trays and incubated for 45 d in a growth chamber set at seasonally adjusted average day lengths and temperatures (Table 1). Soil samples were kept moist and stirred every 10 d to allow optimal germination conditions for the largest number of seeds possible. Emerged burning nettle seedlings were identified, counted, and removed (Shem-Tov and Fennimore 2003). After 45 d of incubation in the growth chamber, the soils were air-dried and weighed, and three 500-g subsamples were removed. Weed seeds were extracted from the 500-g subsamples using a 250-μm screen (60 mesh) custom-built elutriator previously described by Battista (1998). The elutriated samples were sieved through a 1.7-mm screen (12 mesh) to remove coarse soil particles. After the coarse soil particles were discarded, a salt floatation procedure similar to that described by Malone (1967) was used to separate the weed seed from the remaining soil. The viability of elutriated seed was tested by applying pressure, and firm seed were considered viable (Shem-Tov and Fennimore 2003). Total soil seedbank was the sum of germinated seedlings plus viable seeds in the soil. Final seedbank values were the average of the three subsamples and were extrapolated to a square meter basis.

Statistical Analysis. There were no subplot effects, and data were pooled. Data of field emergence and seedbank were log-transformed. A Poisson distribution was assumed, for which the variability in the response increases as the mean increases. A Generalized Additive Model (GAM; Van Klinken and Flack 2005) was then fitted,

$$Y_i = m + a + f(X_i) \qquad [4]$$

where Y is the log of field-emerged seedlings and total seedbank on the ith Julian date, μ is the baseline effect (mean value), α as the year effect, and $f(X_i)$ is the time (Julian date) effect. To account for the variable time between samples, an offset function that normalizes the counts relative to the time since the previous sampling was used. Analysis was conducted using the GAM function, which allows a separate hypothesis test (linear and spline) to detect the effect of time (seasonal patterns) on field germination and seedbank.

Seed Production Study. The study was conducted at the U.S. Department of Agriculture Agricultural Research Station at Salinas, CA. The study

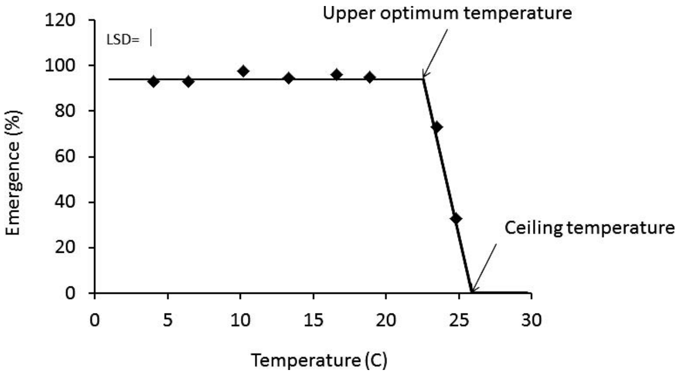

Figure 2. Relationship between temperature (C) and burning nettle final emergence (%). Shown is the upper optimum germination temperature and temperature ceiling above which germination does not occur.

consisted of eight planting dates: February, March, May, June, August, September, November, and December. Each planting date was repeated twice between 2002 and 2004. On each date, three sets of four pots (8-cm diam) were filled with sterilized potting soil and seeded with five nettle seeds per pot at 1 cm depth (total of 12 pots). Seven days after emergence, burning nettle plants were thinned to one plant per pot. The pots were buried at soil level in three microplots. Pots were watered and fertilized as needed to avoid any water or nutrient stresses.

The date of appearance of the first open flower was recorded. Beginning 1 wk after the first open flower, plants were cut and dried in paper bags in a greenhouse at weekly intervals over 3 wk. Seeds produced by these plants were collected, counted, and tested with tetrazolium to assess viability. Air temperature was recorded hourly from the California Irrigation Management Information System weather station network (CIMIS 2015). Temperatures were converted to GDD (McMaster and Wilhelm 1997). Data from March, May, June, August, and September planting dates was used. The number of viable seeds for each set was averaged over the four pots. GDD values were regressed against the number of viable seeds using PROC REG. The critical date for burning nettle removal was set as the intercept of the regression line with the GDD (*x* axis); the respective SE value was estimated using Equation 2.

Results and Discussion

The trapezoid pattern regression was significant ($P < 0.001$), and the upper optimum temperature for burning nettle germination was 22.8 C (Figure 2). However, between 4 C and 22.8 C the final germination percentage was relatively constant, from 93% to 98%, without significant differences among temperatures. The lowest emergence (33%) was observed at 25 C ($P < 0.0001$). The ceiling temperature, above which germination is zero, was set to 25.9 C (Figure 2). These results indicate that burning nettle seeds can germinate over a wide range of temperatures, and under favorable conditions, they can reach more than 90% germination. Table 2 lists the average monthly temperatures and precipitation values in the Salinas Valley area measured over a more than 10-yr period (WRCC 2009). Because seasonal variations in air temperature in this area are moderate, it can be assumed that temperature would not be a limiting factor for burning nettle germination throughout the year.

Table 2. Average monthly temperature and precipitation values measured in Salinas, CA, between July 1996 and December 2008. Data were received from the Western Regional Climate Center (WRCC 2009), Salinas Municipal Airport Weather station.

Month	Temperature	Precipitation
	C	mm
January	10.4	74
February	11.2	71
March	12.4	39
April	13.0	29
May	15.1	9
June	16.3	1
July	17.2	0
August	17.5	0
September	17.4	1
October	15.7	17
November	13.1	28
December	10.4	59

In the field, burning nettle germination was observed at all evaluation timings throughout the year (Figure 3A), and seedling densities ranged from 9 to 581 seedlings m^{-2} (data not shown). Furthermore, germination was continuous, and there was no significant difference in the variation of burning nettle emergence throughout the year (Figure 3A); the effect of time on field germination was not significant ($P = 0.53$). Average air temperature during the field study ranged between 10.4 and 17.4 C (data not shown), ideal for burning nettle, and helps explain the continuous emergence.

Burning nettle seedbank densities varied during the study, and the effect of time on the seedbank was significant ($P = 0.0248$). The highest seedbank densities were observed in the first 100 Julian days of the year, ~7,000 seeds m^{-2}, and a reduction was

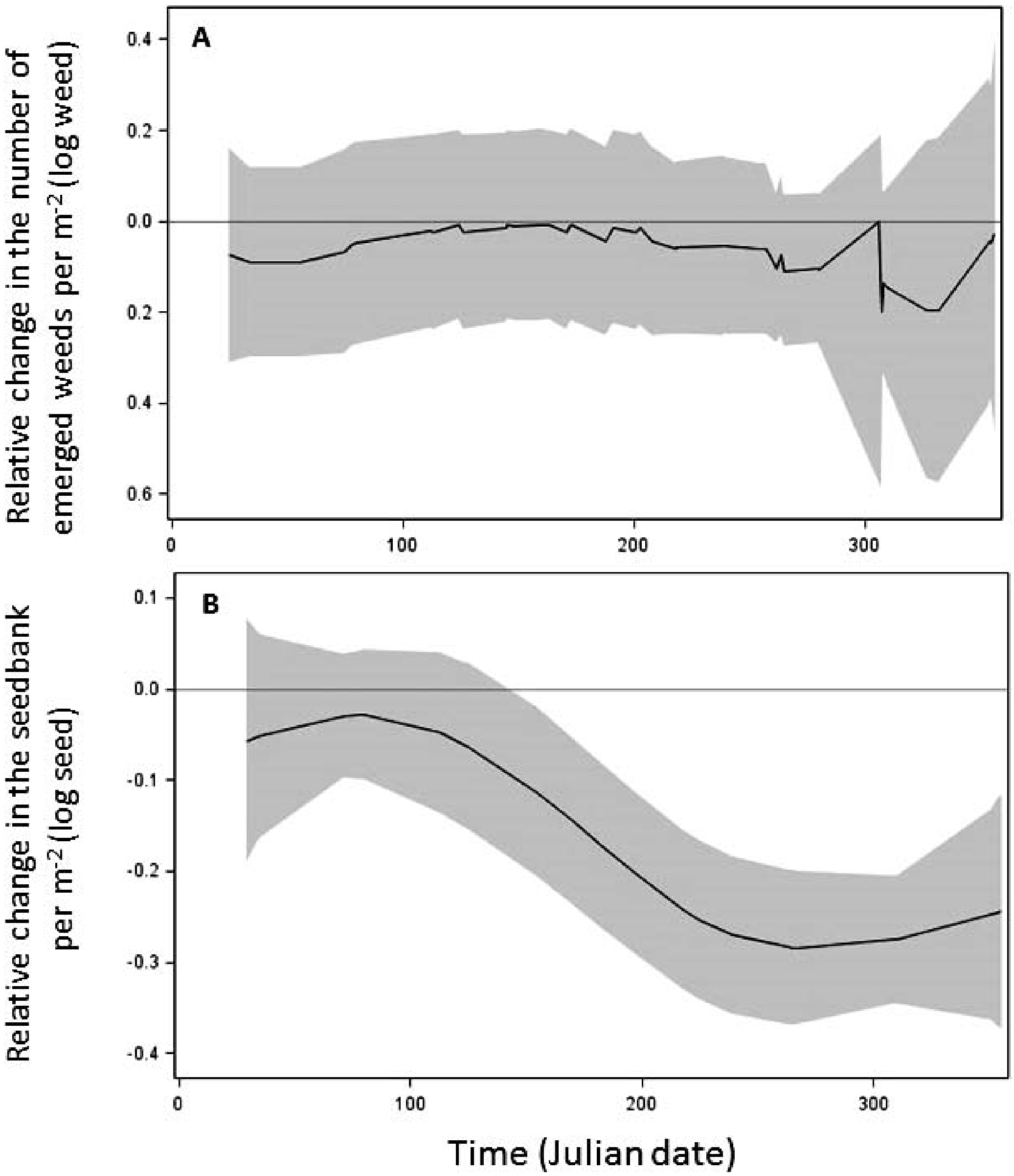

Figure 3. Relationship between time (Julian date between 1 and 365) and relative change in the number (log) of emerged burning nettle seedlings in the field (A), and seedbank density (B) resulting from the Generalized Additive Model. Solid line is the fitted values at a given Julian date. The gray area is the 95% confidence interval.

observed after this date through the year (Figure 3B). The lowest seedbank densities, ~600 seeds m^{-2}, were observed in the last 100 Julian days. These results suggest that the seedbank is not the limiting factor for burning nettle establishment in this area, because germinable seeds are in the seedbank throughout the year. Minimal seed production from December to February was likely due to low temperatures and high precipitation compared with the higher level of seed production from March to September during warmer weather. However, there was no correlation between seedbank densities and field emergence (data not shown).

Weed emergence in many environments is limited to specific seasons of the year (Egley and Williams 1991). Weeds are typically classified as summer and winter annuals according to time of seedling emergence (Radosevich et al. 1997). Burning nettle is considered a "winter" annual in areas with a warm climate, like Israel, the Central Valley of California, and parts of Argentina (Abu-Irmaileh 1991; Poggio 2005; UCIPM 2015), whereas in areas with cooler climates, like Sweden, Germany, and Denmark, it is classified as a "summer" annual (Andreasen and Skovgaard 2009; Hanzlik and Gerowitt 2011; Milberg and Andersson 1998). Results from this study show that

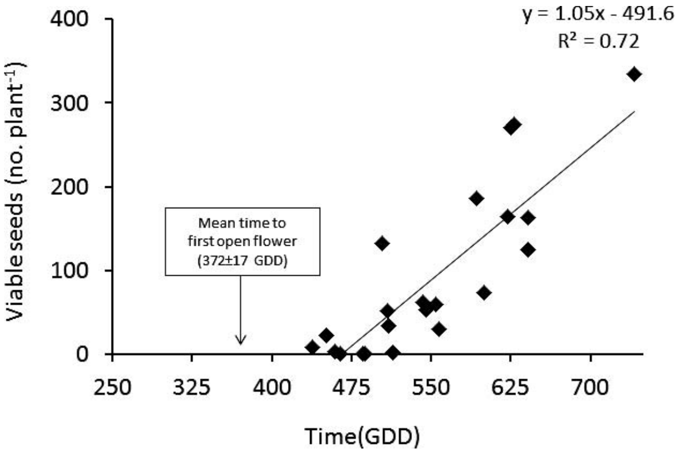

Figure 4. Relationship between time in growing degree days (GDD) and number of burning nettle viable seeds per plant.

this classification is not suitable for burning nettle populations on the Central Coast of California. The moderate climate in this area (Table 2) has temperatures that allow emergence of burning nettle in all seasons. A nonseasonal germination pattern was also observed in other weeds growing in this area, such common chickweed [*Stellaria media* (L.) Vill.] and shepherd's-purse (SA Fennimore, personal observation), whereas other species, like annual bluegrass, maintained a seasonal germination pattern (Shem-Tov and Fennimore 2003).

The burning nettle T_b was determined to be 3 ± 0.2 C (Figure 1B). The highest and lowest GRs were observed at 19 and 4 C, respectively. At temperatures above 19 C, a reduction in burning nettle GR was observed (data not shown). Evaluation of T_b is essential to develop GDD-based models that predict phenological stages in the burning nettle growth cycle. Such models can support decision making regarding the control of this weed and can be implemented in varied environments.

The seed production study showed that burning nettle can set viable seeds throughout the year. This weed has a relatively short growth cycle with the ability to set flower in a period of 372 ± 17 GDD (Figure 4). Daily GDD sum in the high summer in the Salinas valley (August to September) can reach approximately 18 units, and this phenological growth stage can be as short as 20 d. In the cool season, between November and February, first flowering timing can be as long as 60 d. Similar results were observed by Boot et al. (1986), which reported that burning nettle first flowering can occurred between 20 to 32 d after germination. These results provide another indication why burning nettle is well adapted to the local agricultural systems, which are dominated by short-cycle crops of as little as 33 d for spinach (Lati et al. 2015; Shem-Tov and Fennimore 2003).

Burning nettle demonstrated high phenotypic plasticity; it has adjusted its growth cycle and phenological events to the local climate (Merilä and Hendry 2014), and because of moderate temperatures, it was able to germinate and complete a growth cycle in any given season. Evidence for the high plasticity of burning nettle was also reported by Fitter et al. (1995). These authors conducted a 36-yr survey and observed that burning nettle is a species with one of the highest variations in its timing of first flower (124 d), which shifts according to temperature any given year. Other evidence for burning nettle plasticity is the ceiling temperature observed in our petri dish study of 25.9 C (Figure 2) compared with 25 C optimal temperature observed by Lauer (1953). We used seeds collected from local populations, whereas the Lauer (1953) study was conducted on populations collected in southern Germany, where the average summer temperatures can reach 25 C. Less than 1 C difference between optimum and zero germination temperatures of two populations from different environmental conditions demonstrates the high plasticity of this species.

The time to first viable seed set (the *x* intercept) was considered to be the latest time that new seed production can be prevented. This critical time and its SE value were set to 466 ± 13 GDD (Figure 4). Data analysis was based on planting dates from the main growing season in the Salinas Valley (between March and September), which makes this critical timing relevant and accurate for vegetable production in this area. A critical timing for burning nettle removal is relevant for lettuce, which is harvested between 60 and 85 d after seeding and is hand weeded and cultivated twice in each growth cycle. Roberts and Feast (1973) showed that cultivation is important for control of burning nettle, because this treatment can reduce the seedbank in the long term by 35% compared with undisturbed soil. However, delayed cultivation or hand weeding may allow burning nettle to set viable seeds, which will make weed removal less effective at reducing seed return. For fresh spinach, in which cultivation is not an option, this timing is relevant for hand weeding that takes place right before harvest.

When phenmedipham ED_{90} and time (GDD) values from Table 3 were analyzed, a strong linear relationship was observed ($y = 4.75x - 795.7$, $R^2 =$

Table 3. Coefficient estimates and 95% confidence intervals (CI) from the log-logistic regression[a] (dose response) between burning nettle dry weight (% of control) and phenmedipham rate and their respective coefficients of determination (R^2), probability values (P), and phenmedipham rates providing 90% burning nettle control (ED_{90}). Evaluations were made at 10, 20, and 30 d after seeding (DAS) with different growing degree day (GDD) values.

				Coefficients						
DAS	GDD	P	R^2	a	95% CI	b	95% CI	x_0	95% CI	ED_{90}
10	176	< 0.0001	0.97	40.9	(15.0, 66.9)	1.6	(1.3, 1.9)	13.2	(4.1, 22.3)	52
20	349	< 0.0001	0.96	76.2	(61.0, 91.3)	1.4	(0.6, 2.1)	175.2	(81.5, 268.9)	841
30	482	< 0.0001	0.94	82.2	(70.2, 94.3)	2.6	(0.6, 4.7)	649.2	(413.7, 884.8)	1,511

[a] Log-logistic equation $y = m/1 + (x/x_0)^b$.

0.99, P = 0.018), indicating that phenmedipham rates of 550 g ha^{-1} or less will control burning nettle in early growth stages. Based on this analysis, we suggest that phenmedipham be applied no later than 205 GDD (about 14 d in midsummer) using 180 g ha^{-1}. This suggestion is compatible with Lati et al. (2016) who showed that applying phenmedipham to spinach at the two-leaf stage (about 12 d in midsummer) at 180 g ha^{-1} after cycloate PRE is safe for the crop and can reduce weed density by 88% compared with cycloate alone. Dose–response experiments were held under varying temperature and light conditions, and results presented here are valid for the entire growing season in the Salinas Valley. Because phenmedipham is a photosystem II inhibitor, areas with extreme light conditions should validate this application timing. ED_{90} in the first evaluation (176 GDD or 10 DAS) was 52 g ha^{-1} (Table 3), but fresh spinach is highly sensitive to phenmedipham at such early growth stages; therefore, this application timing is not suggested (Anonymous 2015b; RF Smith, personal knowledge). The ED_{90} in the last evaluation (482 GDD or 30 DAS) was 1,510 g ha^{-1}, three times higher than the label rate (Table 3).

This study provides basic biological and ecological information about burning nettle, which helps elucidate how this weed has adapted to California Central Coast conditions and has become an endemic weed in the region. Results presented here can support decisions made as to the timing of weed removal operations for burning nettle. By doing so, the effect of this weed at hand weeding and harvesting time can be reduced, which will promote more viable economic and environmental lettuce and fresh spinach production. Optimal phenmedipham application timings can improve burning nettle control in the short term and can be useful for other phenmedipham-labeled crops. Optimal cultivation and hand weeding time can reduce this weed seedbank, improve its control over the long term, and be highly useful for organic systems, vegetable areas outside California, and other vegetable crops like broccoli (*Brassica oleracea* L.) and celery [*Apium graveolens* L. var. *dulce* (Mill.) Pers.].

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