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The effect of an irrigated buckwheat cover crop on grape vine productivity, and beneficial insect and grape pest abundance in southern California

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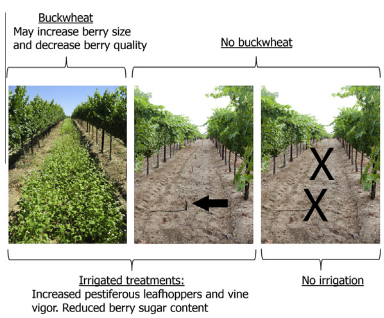
HIGHLIGHTS

- Treatments: irrigated buckwheat (BW); irrigation, no BW; control, no irrigation or BW.
- Irrigated BW cover crop may enhance the abundance of predatory thrips and predators.
- Pestiferous leafhoppers were 129–240% higher in irrigated BW and irrigated plots.
- Vine vigor was increased and berry sugar reduced in both irrigated treatments.
- Irrigated BW may increase berry size, decrease berry quality and lead to penalties for excess water use.

GRAPHICAL ABSTRACT



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ABSTRACT

The effect of an irrigated buckwheat cover crop on populations of beneficial insects and grape pests, vine growth, grape yield, and berry quality was investigated over 1 year in a commercial organic vineyard in southern California, USA. Buckwheat was grown in the spring and summer with additional irrigation that supplemented prevailing vine watering regimens. Treatments replicated four, three and six times respectively were: (1) buckwheat cover crop with supplemental irrigation between vine rows; (2) supplemental irrigation with no buckwheat cover crop; and (3) control plots with no buckwheat cover crop or supplemental irrigation. Flowering buckwheat was extremely attractive to beneficial insects at the beginning of the trial, resulting in 27 times more insects captured from shake sampling, compared with grape foliage in control plots. Results from sticky trap and visual count data indicated that buckwheat may enhance the abundance of generalist predators at certain times. However, densities of pestiferous leafhoppers on grape leaves in August was significantly higher (129–240% greater) in irrigated buckwheat and irrigated plots lacking buckwheat when compared with control plots. This increase in leafhopper density may be attributed to these pests preferring well-irrigated, vigorously growing vines. Mean cane weight was 222% and 170% greater for vines in irrigated buckwheat and irrigated plots lacking buckwheat, respectively, compared with controls indicating that vine vigor increased with supplemental irrigation. An irrigated buckwheat cover crop increased berry size, on average, by 0.67 mm for berries harvested on the side of the row that contained buckwheat, and reduced sugar content of berries by 3.2° Brix, compared with non-irrigated controls. Additionally, the buckwheat cover crop was associated with reduced berry quality because of insect feeding damage.

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Under drought conditions and water shortages, supplemental irrigation to support cover crops may result in water use penalties. Irrigated cover cropping during summer months may not be a viable pest management option for grape growers in southern California.

1. Introduction

Predatory and parasitic invertebrates can benefit from plant-based resources such as nectar and pollen, alternative hosts/prey, shelter, and mating sites (Gurr et al., 2004; Heimpel and Jervis, 2005). Floral and extrafloral nectar can maximize the longevity, fecundity, searching activity and parasitism/predation rates of most natural enemies, and beneficial insect sex ratios may become female biased as a result of these resources (Berndt and Wratten, 2005; Kost and Heil, 2005; Irvin et al., 2006; Hogg et al., 2011). Incorporating nectar producing cover crops in orchards and vineyards is potentially one way to enhance populations of beneficial insects in agricultural systems with the intention of improving pest control by providing natural enemies with nutritive resources (Gurr et al., 2004). Cover crops have been shown to enhance populations of natural enemies of vineyard pests which in turn reduced spider mite and leafhopper populations infesting grapes (Hanna et al., 1996; Nicholls et al., 2000; English-Loeb et al., 2003). Over a 4 year period in juice and table grape vineyards, Costello and Daane (1998) demonstrated that densities of third generation leafhopper nymphs were significantly lower in cover cropped plots compared to control plots. In some years, natural enemies maintained pest densities in cover crop plots below economic thresholds. Cover crops are recommended for soil management by the Californian wine industry which promotes sustainable practices through the Code of Sustainable Winegrowing Workbook (CSWW) because they can maintain soil quality, reduce erosion, and suppress weed growth (CSWA, Wine Institute, and CAWG, 2012).

In northern California, winter vegetation dries early in the grape growing season (i.e., by May) or is mowed or plowed under around June (Altieri et al., 2010). This weed management practice results in vineyards becoming large grape monocultures that lack diverse flora during summer months (i.e., July–September). Therefore, habitat management practices have been developed in Napa and Sonoma counties in northern California which involve intercropping five plant species to ensure flowering cover crops bloom in sequence throughout the season, of which buckwheat (Fagopyrum esculentum Moench [Caryophyllales: Polgonaceae]), is one (Altieri et al., 2010). These cover crop plantings are associated with decreasing pest densities when good establishment of flowering ground cover occurs (Altieri et al., 2010). Supplemental irrigation may be needed to keep buckwheat flowering (Altieri, Pers. Commun.). It is unknown whether this additional irrigation to maintain the cover crop effects vine vigor, grape yield, or berry quality.

In southern California, arid conditions during spring (i.e., March–May) also cause resident winter vegetation to die thereby limiting resources for beneficial insects in vineyards. Maintaining a 'nectar cover crop' in southern California vineyards throughout the spring and summer through additional irrigation may enhance populations of beneficial insects, thereby resulting in lower pest densities. Beneficial insects that may be present in vineyards and enhanced through nectar cover cropping include parasitoids (e.g., *Gonatocerus* spp., parasitoids of sharpshooter eggs, and *Anagrus erythroneurae* Triapitzyn and Chiappini, a parasitoid of leafhopper eggs; both are mymarids) and generalist predators (e.g., anthocorids, coccinellids, chrysopoids and arachnids) (Van Driesche et al., 2008). Key pests of grapes in California include leafhoppers (Hemiptera: Cicadellidae), mites (Acari: Tetranychidae) and thrips (Thysanoptera: Thripidae) (CSWA, Wine Institute, and CAWG, 2012). Sharpshooters (Hemiptera: Cicadellidae) are significant pests of grape in California due to their ability to vector Xylella fastidiosa Wells et al., a xylem-dwelling plant pathogenic bacterium that causes Pierce's Disease, a lethal malady of grapes (Freitag et al., 1952; Kaloostian et al., 1962; Blua et al., 1999). Other herbivore pests such as honeydew producing hemipterans like mealybugs (Hemiptera: Pseudococcidae), psyllids (Hemiptera: Psyllidae) and aphids (Hemiptera: Aphididae) can be pestiferous in vineyards (Bettiga, 2013), especially if they develop mutualisms with ants which disrupt biological control (Serra et al., 2006; Vanek and Potter, 2010; Navarrete et al., 2013).

Flowering cover crops may be attractive to pest species (Nilsson et al., 2011) or result in increased fitness of pest herbivores (Baggen et al., 1999; Begum et al., 2006; Lavandero et al., 2006; Nilsson et al., 2011). If cover crops are to be used in vineyards in southern California to enhance beneficial insect activity, it is important to select plant species that will support natural enemies while simultaneously having no detrimental effects on pest abundance, vine growth, yield, or grape quality. One potentially beneficial cover crop is buckwheat, which has been shown to enhance natural enemy reproduction and efficacy (Nicholls et al., 2000; Berndt et al., 2002; English-Loeb et al., 2003; Irvin et al., 2014). Other attributes favoring the selection of buckwheat are inexpensive seed that is readily available and germinates easily, it tolerates poor growing conditions and has a short sowing to flowering time (Angus et al., 1982; Bowie et al., 1995). Additionally, field trials resulted in the recommendation of buckwheat as a cover crop plant for enhancing beneficial insects in crops grown in arid soils in the southwestern USA (Grasswitz, 2013).

The studies reported here investigated the use of buckwheat as an irrigated spring and summer cover crop in a commercial organic vineyard in southern California. The effect of cover cropping on populations of beneficial insects and grape pests, vine growth, grape yield, and berry quality was determined.

2. Materials and methods

2.1. Experimental set up and design

In 2008, thirteen plots (28.7 m × 6 m [2 rows], with at least 36 m spacing between replicates) were selected in four blocks of Cabernet Sauvignon grapes in an organically-certified vineyard in Temecula, California (CA) USA (GPS coordinates: 33° 33′26.18″N × 117° 00′52.12″W; elevation: 499 m) (Fig. 1). Cover crop and control plots were randomly allocated per block, for a total of seven cover crop plots and six control plots. An additional treatment was incorporated as described below due to poor establishment of cover crops. Control plots consisted of six plots maintained under prevailing vineyard practices, which included machine and hand cultivation between rows to remove unwanted weeds, drip irrigation, and no fertilizer or pest control. On 1 May 2008, one side of each cover crop plot was sown with buckwheat (obtained from Outsidepride, Salem, OR) and the second side of the plot was sown on 11 June, 2008. Staggered seeding was done to produce a consistent supply of flowers. In 2009, treatments were re-randomized using the same thirteen plots outlined above and

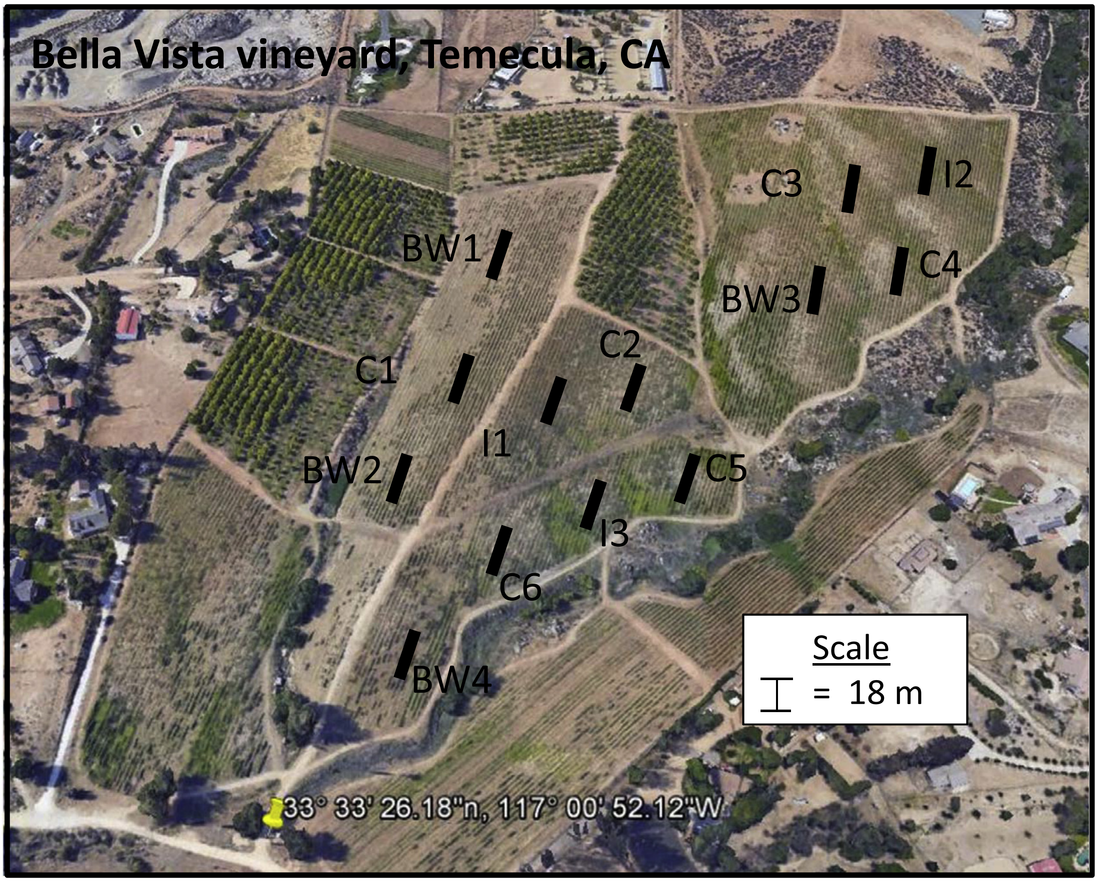

Fig. 1. Layout of experimental plots for a field trial conducted in a vineyard in 2008 investigating the effect of three cover crop treatments (BW = buckwheat cover crop with supplemental irrigation between vine rows; I = supplemental irrigation with no buckwheat cover crop; C = control plots with no buckwheat cover crop or supplemental irrigation) on populations of beneficial insects and grape pests, vine growth, grape yield, and berry quality.

one side of each cover crop plot was sown once with buckwheat seed on 1 April, 2009. The second side the cover crop plot was not sown due to extremely poor establishment which resulted in the discontinuation of the trial in 2009. Buckwheat seed was sown at recommended agricultural sowing rates, which translated to 336 g of buckwheat seed per 60 m^2 plot (approximate area sown). To aid in cover crop establishment and growth, sprinkler irrigation was installed utilizing existing grape irrigation lines in cover crop plots. In 2008, irrigation consisted of 5 sprinklers (blue Micro Bird Spinner sprinkler, 45 L/h, 360° × 3.66 m diameter coverage; Temecula Valley Piping and Supply, Temecula, CA) each installed into 7 mm tubing attached to an 18 cm bamboo stick on each side of the 60 m^2 plot. Plots consisted of two rows, therefore a total of 10 sprinklers per plot were installed. Irrigation sprinkler number and type (8 DIG Micro Sprayers per side of each plot, 50 L/h, 360° × 5.60 m diameter coverage; DIG, Vista, CA) was changed in the second year of the trial to increase spray coverage to increase the likelihood of buckwheat establishment. For each year, buckwheat seed was re-sown on each side of the cover crop plots 2–3 times throughout the trial and each cover crop plot was irrigated for 2 h the day after each sowing to promote germination, then every 7–10 days for approximately 6 h. Additionally, sprinkler irrigation was supplemented with 60.5 L of water per plot, applied via a 60.5 L (16 gal) NorthStar ATV Tree Sprayer (Northern Tool + Equipment, Burnsville, MN) mounted on a 4WD motorbike, approximately three times per week. Information on number of irrigation days and supplemental watering were recorded to estimate the amount of water applied to cover crop plots. In order to protect establishing buckwheat from feeding damage by rabbits, cover crop plots were treated with Rabbit Scram (Enviro Protection Industries Co., Kirkwood, NY) following label directions starting on 25 July in 2008 and 29 April in 2009 and applied monthly for the duration of the trial.

Four out of seven allocated cover crop plots established buckwheat on one side of the row in the 2008 field trial and no replicated plots of buckwheat successfully established in the 2009 field trial. Numerous problems were encountered with establishing and maintaining an experimental cover crop in both years. First, inadequate establishment of cover crops in 2009 was due to inferior quality seed which had a low germination rate (10–33% in greenhouse studies; data not shown). Second, irrigation malfunctions resulted in cover crops receiving too little water due to sprinkler head blockages or flooded plots when irrigation lines were broken (possibly by coyotes chewing on tubing). Third, wild animals caused significant damage to plots with birds eating seeds before they germinated, or rabbits eating large patches of seedlings killing them. Fourth, extreme summer temperatures (multiple consecutive days over 40 °C starting August 31st, 2008) killed seeds and seedlings, and fifth, vineyard maintenance resulted in severe damage to cover crop plants from tractors and vineyard workers walking between rows. Consequently, only results from the 2008 field trial are reported here.

In the 2008 trial, four replicates of the buckwheat cover crop treatment were established. Three additional cover crop plots had irrigation installed, but since buckwheat did not establish, these plots were reassigned as an ‘irrigated treatment without buckwheat’ and used to evaluate potential effects of additional irrigation on insect abundance in the absence of cover crops to account for treatment effects caused by increased water made available to grape vines. Consequently, the three treatments for this 2008 study were: (1) buckwheat cover crop with supplemental irrigation between the vine rows; (2) supplemental irrigation between the vine rows with no buckwheat cover crop; and (3) a control treatment with no buckwheat cover crop or supplemental irrigation between vine rows (Fig. 1).

2.2. Insect monitoring

2.2.1. Sticky traps

Two transparent sticky traps (16.7 cm × 13.2 cm) made from clear Perspex (Plaskolite Inc., Columbus, OH) coated on both sides with Tanglefoot (The Tanglefoot Company, Grand Rapids, MI), were mounted on stakes 1.45 m above the ground with panels parallel to vines. Traps were placed on the north and south side of the middle row of each plot, 3.7 m apart. Transparent traps were used instead of colored sticky traps to avoid biasing trap catches (Horton, 1993; Takasu and Lewis, 1995; Hickman et al., 2001). Traps were collected and replaced weekly over a period of 10 weeks, from 10 June through 19 August 2008. On collection, individual traps were placed between two labeled acetate sheets (21.5 cm × 28 cm, C-line Products, Inc., Mount Prospect, IL) indicating date trap was deployed, treatment, replicate, direction (north or south) and side of trap ('open side' facing out into the plot row or 'foliage side' positioned towards the grape foliage). Traps were stored at −4 °C until captured insects were identified and counted. Traps were examined under a dissecting microscope and all insects were identified to family or genus level. The number of pests and natural enemies were recorded separately for each side of the sticky trap to provide information on whether insects were flying towards or away from the grape canopy and buckwheat cover crop.

Groups of beneficial insects that were counted on sticky traps were parasitic and predatory wasps (Hymenoptera), predatory thrips (Thysanoptera: Aeolothripidae and Thripidae), pirate bugs (Hemiptera: Anthocoridae), ladybugs (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae), big eyed bugs (Hemiptera: Geocoridae), predatory mites (Acari: Phytoseiidae), spiders (Aranae), and ground beetles (Coleoptera: Carabidae). Groups of pest species that were counted on sticky traps were thrips, leafhoppers, (*E. elegantula* Osborn and *E. variabilis* Beamer; [Hemiptera: Cicadellidae]), sharpshooters (*Homalodisca vitripennis* [Germar] and *Homalodisca liturata* Ball [Hemiptera: Cicadellidae]), mirids (Hemiptera: Miridae), false chinch bugs (*Nysius raphanus* [Howard] [Hemiptera: Lygaeidae]), mites, and aphids.

Buckwheat only grew on one side of each cover crop plot, while sticky traps were deployed on both the north and south side of the row within the cover crop plot. Therefore, sticky trap data in cover crop plots was further classified as 'buckwheat present in the plot, but not in the row' and 'buckwheat present in both the plot and row'. Consequently, this data set resulted in a total of four post hoc treatments: (1) control; (2) irrigation treatment; (3) irrigation and buckwheat present in the plot, but not in the row; (4) irrigation and buckwheat present in both the plot and row (all irrigation treatments received water in addition to that being applied to maintain vines).

2.2.2. Statistical analyses of trap data

To simplify analyses, the ten sampling dates associated with sticky trap data were averaged into five distinct bi-weekly time periods. Insect counts were log transformed using $\ln(x+1)$ prior to performing statistical analyses. A linear mixed model in SAS (2008) was used to determine the effect of treatment, row (north versus south side of the row within the plot), side of trap (open side versus foliage side of trap), time period and treatment × time period interaction on the number of combined pests (combining all groups of pests), combined beneficials (parasitic and predatory wasps and predatory thrips) (McCulloch et al., 2008). The plot was considered as a random effect in the model and time was treated as a repeated measure. In insect groups where the treatment × time period interaction term was significant, the effect of treatment was determined separately for each time period. Tukey–Kramer at the 0.05 level of significance was used to separate means (Kramer, 1956). Means (±SEM) presented here were calculated from untransformed data. The mean proportion of each insect group totaling the number of beneficial insects was calculated. Since 95–98% of combined beneficials consisted of parasitic and predatory wasps (Table 1) and means and results were statistically similar for these two groups, results for combined beneficials are presented here.

2.2.3. Visual counts

To obtain visual counts of leafhoppers and predators in the grapevine canopy, a total of five leaves were visually examined per plot every 2 weeks between 5 June and 2 August 2008. Five vines on each of the north and south side were chosen at random in each experimental plot. One first generation leaf (a large, mature leaf located three to four nodes up from the basal node of a cane) per vine was examined with an OptiVisor (Donegan Optical Co., Lenexa KS) and numbers of *E. elegantula* and *E. variabilis*, lacewing eggs, and predators were recorded.

2.2.4. Statistical analyses of visual count data

Visual counts were conducted on both the north and south side of the row within the cover crop plot resulting in the same four post hoc treatments as above. Counts from the five sampled leaves within each row were averaged and used in statistical analyses. Additionally, to simplify analyses, the six sampling dates associated with the visual count data were averaged into three distinct monthly periods (June, July and August). Combined counts for leafhoppers (*E. elegantula* + *E. variabilis*), predators, and lacewing eggs were log transformed using $\ln(x+1)$ prior to analyses. A linear mixed model in SAS (2008) was used to determine the effect of month, row, treatment and month × treatment interaction on leafhopper, predators and lacewing egg counts. In cases where the interaction term was not significant, this variable was removed and the model re-run. Where the month × treatment interaction term was significant, data were analyzed by month and treatment. Tukey–Kramer at the 0.05 level of significance was used to separate means. Means (±SEM) presented here were calculated from untransformed data.

2.2.5. Shake sampling foliage

Shake samples were conducted on flowering buckwheat plots and grape foliage to inventory insects associated with the cover crop. Flowering buckwheat plants and grape foliage in buckwheat and control plots, respectively, were sampled every 2 weeks between 19 June 2008 and 14 August 2008. This was conducted by vigorously shaking foliage into a sweep net (Bioquip, Rancho Dominguez, CA; 40 cm diameter hoop) for 1 min and placing contents in a labeled Ziploc bag. Shake sampling was conducted between 7 am and 11 am. Bags containing samples were placed in a cooler and transported to the laboratory, and stored at −4 °C until insects were counted, identified to family or genus level, and categorized as being either beneficial or pestiferous. Beneficial insects counted in shake net samples included parasitic and predatory wasps, predatory thrips, pirate bugs, ladybugs, lacewings, big eyed bugs, spiders, nabids (Hemiptera: Nabidae) and earwigs (*Forficula auricularia*; Dermaptera: Forficulidae). Pest species counted were thrips, sharpshooters, leafhoppers, ants (Hymenoptera: Formicidae), mirids, false chinch bugs, mites, aphids, psyllids (Hemiptera: Psyllidae), and grasshoppers (Orthoptera).

Table 1
The overall mean percentage of each group of pest species and group of beneficial insect captured on sticky traps deployed and in shake samples conducted in a vineyard between June 10th and August 19th, 2008.

	Sticky traps (%)	Shake samples (%)
Pest		
Thrips	48.65	0.42
Leafhoppers	48.31	91.4
Sharpshooters	0.15	0.60
Mirids	2.04	1.01
False chinch bugs	0.20	0.11
Mites	0.09	0.01
Aphids	0.56	0.04
Ants	0.00	5.91
Other pests	0.00	0.50
Beneficial insect		
Parasitic and predatory wasps	97.46	4.75
Predatory thrips	1.82	3.09
Pirate bugs	0.23	16.39
Ladybugs	0.06	21.85
Lacewings	0.01	3.09
Big eyed bugs	0.04	23.28
Spiders	0.15	19.95
Predatory beetles	0.23	0.00
Earwig	0.00	0.24
Other beneficial insects	0.00	7.36

2.2.6. Statistical analyses of capture data from shake sampling

The effect of treatment (i.e., buckwheat or control) and sample date on combined pests (data log transformed), combined beneficials (square-root transformed), combined leafhoppers (square-root transformed) and ants (log transformed) was determined using a linear mixed model in SAS (2008) as previously described for the visual count data. For sharpshooter counts, which did not fit a normal distribution following transformation, Friedman's Chi-square was used on raw data to determine the effect of treatment at the 0.05 level of significance in SAS (2008) (Conover, 1999). Means (±SEM) presented here were calculated from untransformed data.

2.3. Effect of buckwheat on grape yield and quality and statistical analyses of data

On 18 September 2008, the number of grape clusters present within a 3 m section of vine in the center of each plot was counted. Ten randomly selected clusters were harvested from each section (five each from the north and south sides of the row), placed into labeled Ziploc bags and transported to the laboratory in a cooler for yield and quality measurements. The weight of each cluster was recorded to within 0.01 g and the number of berries per cluster counted. Each berry was inspected and categorized as normal (i.e., healthy), shriveled (i.e., berry shriveled due to dehydration), having broken skin, or crushed (i.e., handling damage). Additionally, 25 berries per cluster were randomly selected from the 'normal' berry category and scored on size, superficial damage (i.e., scaring to skin), and sugar content. Berry size (diameter in mm) was measured for each berry using digital calipers (150 mm Absolute Mode Digital Caliper, Tresna, Guilin Guanglu Measuring Instrument Company, Guangxi Province, China) to within 0.01 mm. Superficial skin damage was measured by inspecting each of the 25 berries for scarring caused by thrips feeding and presence of sooty mold. Finally, all 25 berries were placed into a Ziploc bag and crushed to extract juice. A refractometer (Pocket Refractometer Pal-1, Atago, Itabashi-ku, Tokyo, Japan) was used to measure Brix content (i.e., sugar levels) of extracted juice.

For overall cluster counts, sample position was not row specific, therefore this data set had three treatments: (1) control; (2) irrigation treatment; and (3) irrigation and buckwheat treatment. The remaining grape yield and quality parameters were measured separately for both the north and south side of the row within the cover crop plot, resulting in the four post hoc treatments listed previously. The effect of treatment on the overall number of clusters per 3 m row (data logged transformed) was determined using linear regression (Kutner et al., 2004). The effect of treatment, direction and treatment × direction interaction on weight of clusters (square-root transformed), total number of berries per cluster (raw data), number of 'normal' berries (square-root transformed), Brix content (raw data) and berry size (raw data) was determined using a linear mixed model. To separate means, pairwise t-tests were performed and p-values were adjusted using Tukey's method (Tukey, 1949). A generalized linear mixed model was used to determine effect of treatment, direction and treatment × direction interaction on the number of scarred berries since these data were not normally distributed (McCulloch et al., 2008). For these analyses, plot was treated as a random variable; Poisson distribution was assumed for the number of scarred berries with identity used as a link function. All other dependent variables satisfied the assumptions of a normal distribution. To separate means, pairwise t-tests were performed and p-values were adjusted using Tukey's method. A logistic model was used to determine the effect of treatment and row direction (north or south) on the percentage of broken and shriveled berries. Pairwise comparisons using the logistic model were used to separate means (Hosmer et al., 2013). All statistical tests were conducted at the 0.05 level of significance in SAS (2008). Means (±SEM) presented here were calculated from untransformed data.

2.4. Effect of buckwheat on vine vigor

The influence of irrigation and buckwheat cover cropping on vine vigor was assessed in October 2008 by measuring the weight of winter prunings from three randomly selected vines in the center of each treatment plot. For each vine, the number of canes growing from each arm was recorded. All canes were removed from the vine by cutting just above the basal node and leaves were stripped from canes. Canes from each vine were placed into plastic bags and labeled with treatment and replicate. The contents of each bag were weighed to within 0.01 g and the average weight per cane calculated for each vine by weighing the contents of each bag and dividing the weight by the number of canes.

These data were collected for three treatments: (1) control; (2) irrigation treatment; and (3) irrigation and buckwheat treatment. A linear mixed model with plot as a random factor was fitted first to complement previous analyses; however, plot was not significant so the model was reduced to a one-way Analysis of Variance (ANOVA). The effect of treatment on average cane weight (data logged transformed) was determined using one-way ANOVA in SAS (2008). Tukey's Studentized range test at the 0.05 level of significance was used to separate significant means. Means (±SEM) presented here were calculated from untransformed data.

2.5. Water usage and cost

During the 2008 study, the seven designated cover crop plots were irrigated via sprinkler irrigation installed on existing grape irrigation, plus supplemental watering using a 60.5 L water sprayer up to three times per week. Sprinklers were rated at 45.4 L/h and 5 sprinklers were installed each side of the 30 m long plot (which encompassed two rows). On grape irrigation days, sprinklers irrigated for 6 h emitting 1362 L per side of the plot. Sprinkler and supplemental watering days were recorded and the number of liters of water each plot received was calculated per month and used to calculate the total number of liters used during the trial. Total cost of water consumed by the entire vineyard and cost of water per liter was obtained from water bills issued by the Rancho California Water Board to the vineyard owner. The monthly cost of water used in these experiments was calculated by multiplying the total number of liters used during the trial by the per liter cost of water. Additionally, penalties charged for exceeding the monthly water restrictions imposed by the Rancho California Water Board were recorded and reported here.

3. Results

3.1. Effect of the buckwheat on beneficial insects and grape pests

3.1.1. Sticky traps

Trapped pest species were predominantly thrips and leafhoppers (Table 1). The interaction between time period and treatment on combined pest counts was significant (Table 2). There was no significant effect of treatment on combined pests captured on sticky traps deployed between 10 June 2008 and 5 August 2008 (Fig. 1a). For the last time period, 12 August 2008–19 August 2008, mean combined pest counts per trap were significantly higher (81% greater) in irrigated plots compared to controls (non-irrigated plots) ($F = 5.70$, df = 3, 16.5, $p < 0.01$) (Fig. 2b). When buckwheat was present in the plot, but not the trap row, mean combined pest counts were 77% higher than in control plots. However, this difference was not significant (Fig. 2b).

The majority of beneficial insects on sticky cards were parasitic and predatory wasps, and predators dominated shake samples (Table 1). The leafhopper parasitoid, *A. erythroneurae*, accounted for 95–97% of beneficial Hymenoptera counted on sticky traps. The interaction between time period and treatment on combined beneficial insects was significant (Table 2). For the last two time periods, treatment had a significant effect on combined beneficials (time period 4, 29 July 2008–5 August 2008: $F = 5.34$, df = 3, 16, $p < 0.01$; time period 5, 12 August 2008–19 August 2008: $F = 11.29$, df = 3, 14.5, $p < 0.001$). For both of these time periods, combined beneficial insects was significantly higher (127–167% higher) in irrigated plots compared to controls (Fig. 2a and b). For the last time period (12 August 2008–19 August 2008), combined beneficial insects were significantly higher (105% higher) in plots containing buckwheat near the trap (but not in the trap row), compared with control plots (Fig. 2b).

The time period × treatment interaction on predatory thrips counts was not significant, whereas, treatment and time period had a significant effect on predatory thrips counts (Table 2). Numbers of predatory thrips were significantly higher (up to 126% higher) in plots containing buckwheat near the trap (but not in the trap row), compared with controls and the irrigated treatment (Fig. 3). Numbers of predatory thrips on traps decreased significantly from the beginning of the trial (mean = 7.4 ± 0.62) to the end of the trial (0.61 ± 0.09) (Table 2).

The placement of sticky traps on the north or south side of the vine row had no significant effect on combined pests and combined beneficial insects counted on sticky traps (Table 2). The side of the trap had a significant effect on combined pests and predatory thrips counted on sticky traps (Table 2). These insect groups had

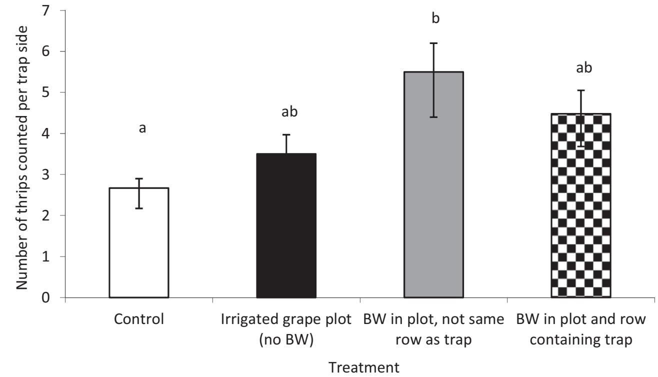

Fig. 3. Mean (±SEM) number of predatory thrips counted on sticky traps deployed in four cover crop treatments in a vineyard during 10 June 2008 to 19 August 2008 (across all time periods) (BW = buckwheat; different letters indicate significant differences [$p < 0.05$] between treatments).

Table 2
Statistical results (*F*-value, Num df, Den df and *p*-value) for linear mixed model determining the effect of treatment, row, side, time period and treatment × time period interaction on the number of different groups of insects captured on sticky traps deployed in a vineyard between June 10th and August 19th, 2008.

Insect group	Treatment	Row	Side	Time period	Treatment × time period
Combined pests	1.11, 3, 13.2, 0.38	0.06, 1, 11.1, 0.81	6.34, 1, 205, 0.01	1.50, 4, 206, 0.20	1.55, 12, 206, 0.05
Combined beneficials	4.47, 3, 13.1, 0.02	1.91, 1, 11, 0.19	3.87, 1, 205, 0.05	402.47, 4, 206, <0.0001	2.08, 12, 206, 0.02
Predatory thrips	4.02, 3, 17.6, 0.02	10.73, 1, 216, 0.001	8.69, 1, 216, 0.004	78.39, 4, 217, <0.0001	1.62, 12, 217, 0.09

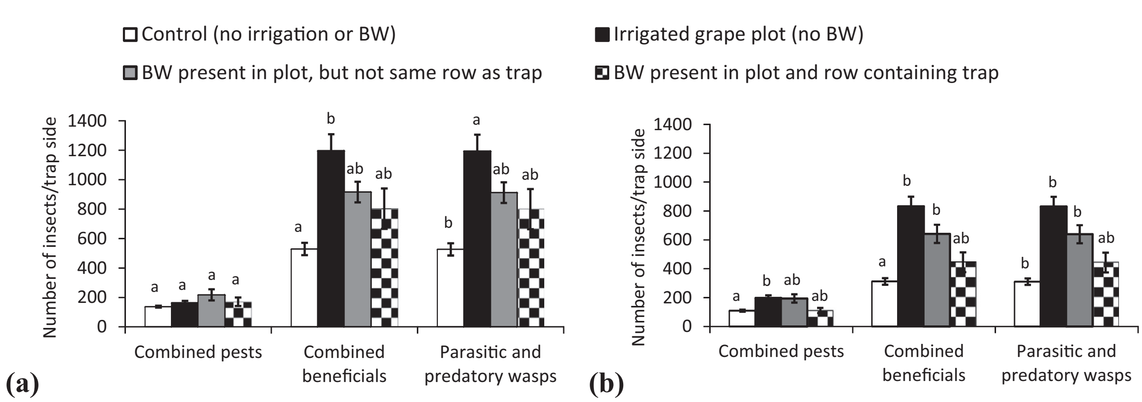

Fig. 2. Mean (±SEM) number of pestiferous and beneficial insects counted on sticky traps deployed in four cover crop treatments in the experimental vineyard during (a) 29 July 2008 and 5 August 2008 (time period 4) and (b) 12 August 2008 and 19 August 2008 (time period 5) (BW = buckwheat; different letters indicate significant differences [$p < 0.05$] between treatments).

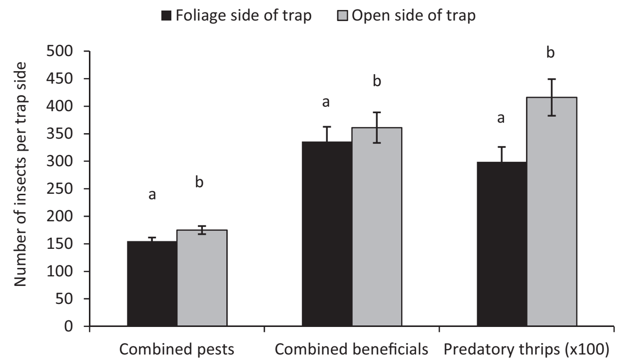

Fig. 4. Effect of trap side on mean numbers of combined pests, combined beneficial insects and predatory thrips counted on sticky traps deployed in a vineyard during 10 June 2008 to 19 August 2008 (across all time periods) (different letters indicate significant differences [$p < 0.05$] between trap sides).

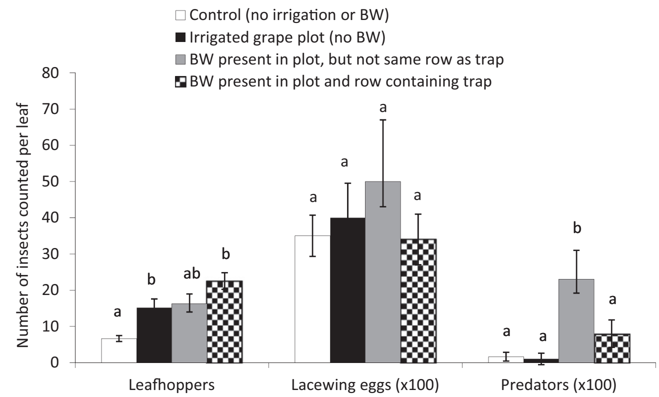

Fig. 5. Mean (±SEM) number of leafhoppers (*E. elegantula* + *E. variabilis*), lacewing eggs and predators counted during visual inspections of grape leaves in four cover crop treatments in a vineyard during August 2008 (BW = buckwheat; different letters indicate significant differences [$p < 0.05$] between treatments).

up to 39% higher densities on the open side of traps compared with the foliage side (Fig. 4), indicating that pest and beneficial insects were predominately immigrating into the grape canopy.

3.1.2. Visual counts

Table 3 shows the effect of month, treatment, month × treatment and row on combined leafhoppers (*E. elegantula* + *E. variabilis*), predators and lacewing eggs counted during visual leaf inspections. The month × treatment interaction had a significant effect for combined leafhopper and predator counts (Table 3). Treatment had a significant effect on combined leafhopper and predator counts in August (leafhopper: $F = 5.23$, df = 3, 17, $p < 0.05$; predator: $F = 12.44$, df = 3, 14, $p < 0.001$), but not for June and July. For August, the combined leafhoppers counted on grape leaves was significantly higher (129–240% higher) in plots where buckwheat was present in the same row as the trap and in irrigated plots compared with controls (Fig. 5). Plots containing buckwheat near the trap contained significantly higher numbers of predators (up to 1150% higher) compared with the three remaining treatments (Fig. 5). There was no significant treatment or month × treatment interaction effect on the numbers of lacewing eggs (Table 3).

3.1.3. Shake sampling

Pest species captured in shake net samples were predominantly leafhoppers and ants (Table 1). Mean combined pests was significantly higher (305–505% higher) on grape foliage in control plots compared with flowering buckwheat plants (Table 4: effect of treatment; Fig. 6). Mean sharpshooter counts per sample were 37 times higher in grape foliage compared with flowering buckwheat plants ($\chi^2 = 2.98$, df = 1, $p < 0.05$) (Fig. 6). That is, only one sharpshooter was captured from shake sampling buckwheat flowers across all dates (four samples) and replicates (16 plots), whereas, shake sampling grape foliage resulted in the capture of 50 sharpshooters (four samples from 22 plots) (i.e., total sharpshooter counts).

When analyzed by date and treatment, treatment had a significant effect on leafhopper counts for all four sampling dates (19 June 2008: $F = 45.12$, df = 1, 7, $p < 0.001$; 10 July 2008: $F = 19.15$, df = 1, 5, $p < 0.01$; 30 July 2008: $F = 19.70$, df = 1, 7, $p < 0.01$; 14 August 2008: $F = 7.81$, df = 1, 7, $p < 0.05$). For all sampling dates, counts of leafhoppers from grape foliage was significantly higher (up to 1760% higher) compared with flowering buckwheat plants (Fig. 7A–D). Treatment had a significant effect on ant counts for samples collected on July 10th, 2008 ($F = 48.01$, df = 1, 4, $p < 0.01$) and 14 August 2008 ($F = 6.56$, df = 1, 7, $p < 0.05$). There was no treatment effect on ant counts for samples collected 19 June 2008 ($F = 1.34$, df = 1, 6, $p = 0.29$) or 30 July 2008 ($F = 1.34$, df = 1, 6, $p = 0.29$). For 10 July and 14 August 2008, counts of ants from grape foliage was 4748% and 4536% higher, respectively, in flowering buckwheat plants compared with grape foliage (Fig. 7B and D).

The predominant beneficial insects captured in shake samples were generalist predators; big-eyed bugs, ladybugs, spiders, and pirate bugs (Table 1). When analyzed by date and treatment, treatment had a significant effect on combined beneficials for the 19 June 2008 sampling date ($F = 13.43$, df = 1, 7, $p < 0.01$). On 19 June 2008, combined beneficials was 2667% higher on flowering buckwheat plants compared with grape foliage (Fig. 7A).

3.2. Effect of buckwheat on grape yield and quality

There was no significant difference in number of grape clusters or mean weight per cluster between treatment plots (number: $F = 0.63$, df = 2, 10, $p = 0.55$; weight: $F = 1.80$, df = 3, 105, $p = 0.07$) (Fig. 8a). Treatment ($F = 1.41$, df = 3, 105, $p = 0.24$) had no significant effect on mean number of berries per cluster (Fig. 8a). Mean Brix content was up to 3.2° higher in control plots compared with the buckwheat plots and the irrigated treatment ($F = 3.91$, df = 3, 105, $p < 0.01$) (Fig. 8a). Berries harvested from the side of the row containing buckwheat plants were significantly larger (i.e., the diameter was on average 0.67 mm or 6.5% bigger) compared with berries harvested from non-irrigated control plots ($F = 2.97$, df = 3, 3096, $p < 0.05$) (Fig. 8b).

Table 3
Statistical results (*F*-value, Num df, Den df and *p*-value) for a linear mixed model analyzing row, month, treatment and month × treatment interaction effects on the number of different insect groups counted during visual inspections of grape leaves between June 19th, 2008 and August 14th, 2008.

Insect group	Row	Month	Treatment	Month × treatment
Combined leafhoppers	1.68, 1,53.7, 0.20	31.18, 2, 54, <0.0001	1.02, 2, 9.58, 0.39	5.40, 4, 54, <0.0001
Predators	0.12, 1, 64, 0.74	0.94, 2, 64, 0.39	6.83, 2, 64, 0.002	3.82, 4, 64, 0.008
Lacewing eggs	11.46, 1, 54.5, 0.001	55.5, 2, 55.5, <0.0001	0.39, 2, 10, 0.7612	0.55, 4, 55.6, 0.70

Table 4
Statistical results (*F*-value, Num df, Den df and *p*-value) for a linear mixed model analyzing date, treatment, interaction and date × treatment interaction effects on the number of different insect groups counted during shake sampling of flowering buckwheat plants (in buckwheat plots) and grape foliage (in control plots) between June 19th, 2008 and August 14th, 2008.

Insect group	Treatment	Date	Date × treatment
Combined beneficials	10.20, 1, 8, 0.01	2.26, 3, 20, 0.11	4.52, 3, 20, 0.01
Combined pests	31.66, 1, 8, 0.001	63.24, 3, 20, <0.0001	1.90, 3, 20, 0.16
Leafhoppers	39.66, 1, 8, 0.001	30.87, 3, 20, <0.0001	13.72, 3, 20, <0.0001
Ants	17.01, 1, 8, 0.003	14.31, 3, 20, <0.0001	13.49, 3, 20, <0.0001

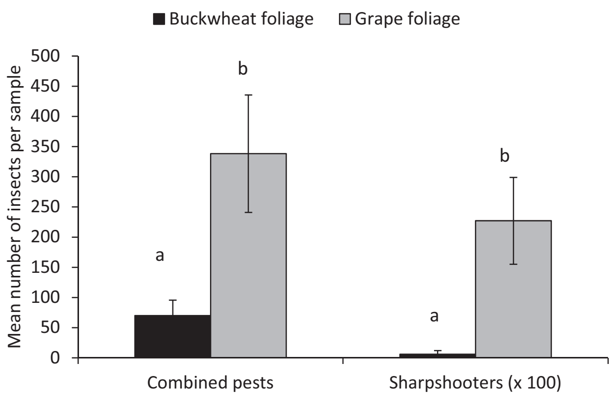

Fig. 6. The effect of plant type on mean (±SEM) numbers of sharpshooters and combined pests captured during 1 min shake samples conducted on flowering buckwheat plants in cover crop plots and grape foliage in control plots between June and August 2008 (different letters indicate significant [$p < 0.05$] differences between plant treatments).

The percentage of berries that were shriveled due to dehydration was up to 11% higher in non-irrigated control plots compared with both treatments receiving supplemental irrigation ($\chi^2 = 288.35$, df = 3, $p < 0.0001$) (Fig. 8b). The percentage of berries with broken skin from insect damage was up to 2% higher in buckwheat plots compared with controls and the irrigated treatment ($\chi^2 = 153.14$, df = 3, $p < 0.0001$) (Fig. 8b). Bees and yellow jackets were observed feeding from berries in buckwheat plots during harvest. The percentage of scarred berries was 10% higher in plots containing buckwheat, but not in the same row of the grapes, compared with controls ($F = 2.71$, df = 3, 105, $p < 0.05$) (Fig. 8b). The side of the row that the grapes were harvested from had no significant effect on any measured grape yield and quality variable. Similarly, there was no significant treatment × row side interaction effect for any grape yield and quality variable ($p > 0.05$).

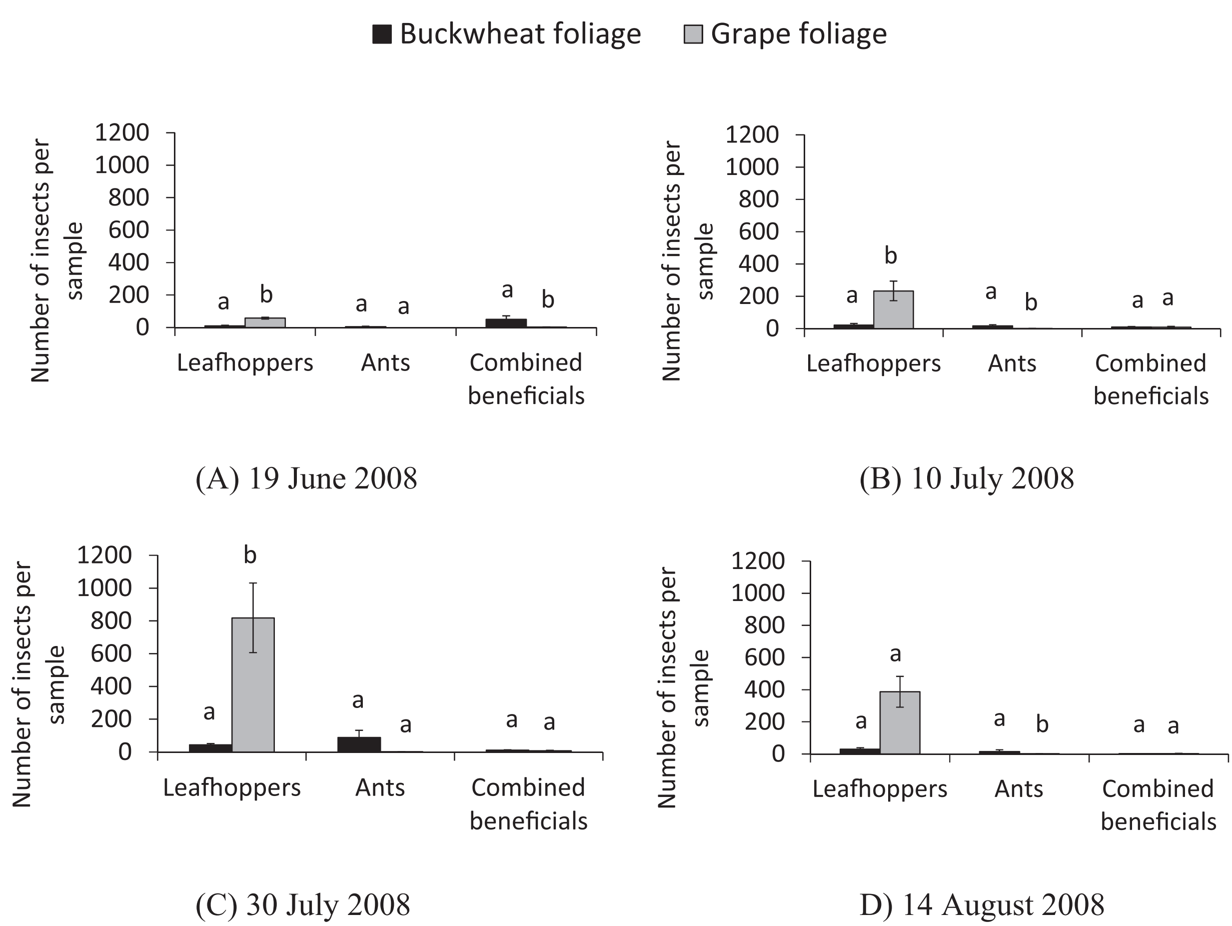

Fig. 7. Mean (±SEM) numbers of three insect groups captured during 1 min shake samples conducted on flowering buckwheat plants in cover crop plots and grape foliage in control plots on four sampling dates (A–D) (different letters indicate a significant difference [$p < 0.05$] in insect numbers between buckwheat and grape foliage).

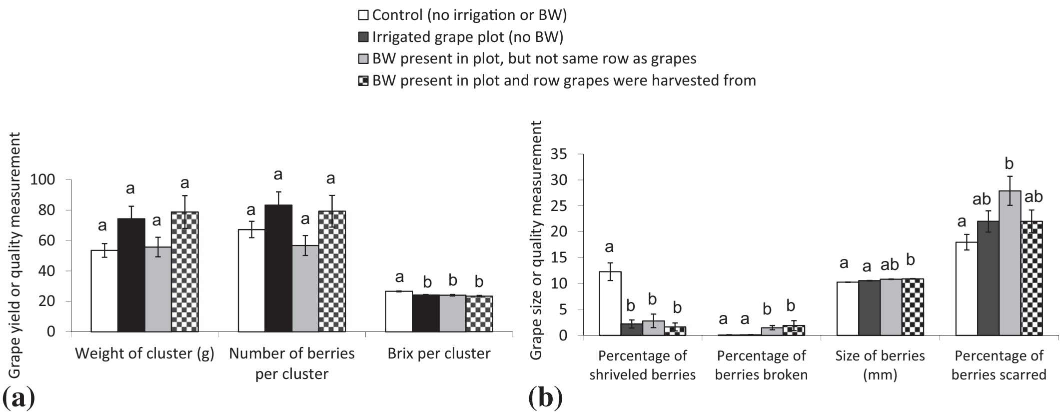

Fig. 8. Mean (±SEM) grape yield and berry quality measurements for grapes harvested from four cover crop treatments in a vineyard on 18 September 2008 (BW = buckwheat; different letters indicate significant differences [$p < 0.05$] between treatments).

Table 5
Water usage and cost of water per month during the irrigated cover cropping trial, and estimated water usage and cost for two cover crop strategies (sown either every 7th row or 11th row) irrigated with sprinklers installed on existing grape irrigation within a 16.2 ha vineyard (approximately 176 rows × 485.2 m long).

	March	April	May	June	July	August	September	Total
Water usage and cost for the cover crop trial								
Number of liters of water used by one row of each plot (30 m × 2 rows)	272	1763	2142	1631	2649	3039	0	11,496
Total number of liters used during trial	3816	24,680	59,961	44,638	74,194	84,127	0	291,416
Price per liter	0.000375	0.000375	0.000375	0.000375	0.000375	0.000375	0.000375	
Cost of trial per month	$1.43	$9.26	$22.49	$16.74	$27.82	$31.55	$0	$109.28
Penalties charged for breaching water restrictions	$0	$0	$0	$66	$3647	$3100	$3206	$10,019
Estimated water usage and cost for two cover crop strategies								
Liters used to sow 16.2 ha, 1 row in 7	0	1,121,020	1,494,693	1,195,754	1,918,189	2,167,304	0	7,896,960
Cost of 16.2 ha, sowing 1 row in 7		$420	$561	$448	$719	$813	$0	$2961
Liters used to sow 16.2 ha, 1 row in 11	0	713,455	951,279	761,020	1,220,804	1,379,352	0	5,025,910
Cost of 16.2 ha, sowing 1 row in 11		$268	$357	$285	$458	$517	$0	$1885

3.3. Effect of buckwheat on vine vigor

Mean cane weight was 222% and 170% higher in the irrigated (mean = 36 g ± 11) and buckwheat (30 g ± 4) treatments, respectively, compared with the control plots (11 g ± 1) ($F = 12.85$, df = 2, 35, $p < 0.0001$).

3.4. Water usage and cost

One 30 m side of each plot received between 272 and 3039 L of water each month (Table 5) and by May 2008 both sides (rows) of the plot were watered. The estimated total number of liters the seven irrigated plots received during the trial was 291,416 L (Table 5). The cost of water was approximately 0.000375 cents per liter, amounting to $109.28 for the entire trial (Table 5). Water usage in field trials amounted to 0.7% of total water consumption during March–August 2008. During June–September 2008, the cooperating winery was charged a total of $10, 019 for exceeding monthly water allocations (Table 5), this was not attributable to this experiment.

Water use analyses indicated that for strategy (1) where 1 row in every 7 is sown with a cover crop, estimated water usage would be 7,896,960 L, costing $2961 (Table 5). This water usage would increase water consumption during March–August by 18%. For strategy (2), where 1 row in every 11 is sown with cover crops, water usage was estimated at 5,025,910 L, costing $1885 (Table 5). This water usage would increase water consumption during March–August by 11%.

4. Discussion

4.1. Effect of the buckwheat cover crop on beneficial insects and grape pests

Cover crops providing floral resources may enhance biological control of grape pests by attracting and retaining beneficial insects (Landis et al., 2000; Gurr et al., 2004), and increasing their fitness as a result of access to nectar and pollen (Irvin et al., 2014). This in turn may increase parasitism and predation rates of pest species (Géneau et al., 2012; Hogg et al., 2011). The current study aimed to determine whether growing a nectar cover crop can attract beneficial insects and lead to enhanced biological control of grape pests in an organic vineyard in southern California. Results from sticky trap captures indicated that beneficial insects immigrated into the grape canopy along with pests. Buckwheat was extremely attractive to beneficial insects when captures were compared with grape foliage. Sticky trap and visual count data suggested that buckwheat enhanced the abundance of generalist predators on some sample dates. However, the irrigated cover crop led to increased pest populations including pestiferous leafhoppers. This increase in leafhopper density may be attributed to these pests preferring well-irrigated, vigorously growing vines (Daane et al., 1995). Mean cane weight was 222% and 170% greater for vines in the buckwheat and irrigated treatments, respectively, compared with non-irrigated controls indicating that vine vigor increased in experimental plots receiving supplemental irrigation.

Sticky trap data suggested that irrigated plots lacking buckwheat resulted in higher pest numbers compared with non-irrigated controls as the growing season progressed. However, when supplemental irrigation was coupled with a buckwheat cover crop, pest numbers were statistically equivalent to control plots that did not receive supplemental irrigation. The combined effect of buckwheat and supplemental irrigation, appears to have neutralized the negative effects of supplemental irrigation on pest populations. This outcome may have been due, in part, to increased numbers of generalist predators on some sample dates (supported by sticky trap and visual count data) inhabiting buckwheat plots. In addition to enhancing numbers of beneficial insects, pollen and nectar from flowering buckwheat plants may have increased the longevity and fecundity of natural enemies (Irvin et al., 2014; Irvin and Hoddle, 2015). Weeds growing in irrigated plots lacking buckwheat may have acted as "cover crops" and attracted pest and beneficial insect species (Silva et al., 2010).

Habitat diversification can result in elevated pest numbers and increased crop damage in agricultural systems (Zhao et al., 1992; Romeis et al., 2005). Cover crop plants may increase damage caused by herbivores by harboring primary and secondary pests (Wilde, 1970; Costello and Daane, 1998), enhancing fitness of pest herbivores (Baggen et al., 1999; Begum et al., 2006; Lavandero et al., 2006), increasing fourth-trophic-level processes (Stephens et al., 1998), or masking odors which natural enemies use to find hosts (Price, 1981). Results from shake sampling of flowering buckwheat plants and grape foliage showed that buckwheat was consistently less attractive to pest cicadellids compared with grape foliage. This result suggests that a buckwheat cover crop may not harbor large numbers of cicadellids that could disperse into grape foliage. However, sharpshooter species, such as *H. vitripennis* and *H. liturata* Ball (Cicadellidae), are significant pests of grapes in California due to their ability to vector X. fastidiosa (Freitag et al., 1952; Kaloostian et al., 1962; Blua et al., 1999). Buckwheat is a host of *X. fastidiosa* and *H. vitripennis* can successfully transmit *X. fastidiosa* from buckwheat to grapevines (Irvin et al., 2014). This indicates that even low densities of certain pest species, like sharpshooters, inhabiting a cover crop may pose an unacceptable economic threat to grape producers. Shake sampling indicated that flowering buckwheat plants harbor ants, which are known to feed on the nectar of flowering plants. The presence of ants in vineyards may disrupt biological control of scales, mealybugs, aphids, and psyllids because they develop mutualisms in which hemipterans "reward" ants with honeydew. This often necessitates implementation of control measures because hemipteran numbers increase due to ants interfering with natural enemies (Serra et al., 2006; Vanek and Potter, 2010; Navarrete et al., 2013).

4.2. Effect of buckwheat on grape yield and quality

Silvestre et al. (2012) demonstrated that non-irrigated cover crops can compete with the grapevines for water and nitrogen, thereby reducing vine vigor and grape yield. Conversely, other studies showed no effect of cover crops on grape yield (Caspari et al., 1997). In the current study, an irrigated buckwheat cover crop increased berry size on one side of the buckwheat plot and reduced Brix content of berries by 3°, when compared with control plots that did not receive supplemental irrigation. Increased berry size and reduced Brix content was likely attributable to extra water used to sustain the buckwheat cover crop plots. Red wines (this work was done in a Cabernet Sauvignon vineyard) are generally made from grapes with a ripeness measure between 18° and 25° Brix (Hornsey, 2007). Mean Brix content of grapes harvested from treatments in this study ranged between 23° and 26°, suggesting that irrigation treatments likely had significant negative effects on grape quality. Additional irrigation may have directly increased berry size and diluted sugars in the berries, or indirectly affected these parameters by increasing vine vigor, thereby decreasing the amount of sunlight reaching the berries. Caspari et al. (1997) similarly found that higher irrigation regimes decreased the sugar/acid ratio in grapes compared with deficit irrigation. Increased vine vigor and reduced sugar content of grapes because of the need to irrigate cover crops may not be desirable for wine and table grape growers. Wines made from highly vigorous vines may have less sensory attributes during wine tasting and lower ethanol content compared with wines made from low vigor vines of the same variety (Filippetti et al., 2013).

Additionally, an irrigated buckwheat cover crop led to reductions in berry quality. Up to 2% more berries had skin broken from bee and yellow jacket feeding, and 10% more berries were scarred from thrips feeding. Feeding by larval and adult thrips can scar immature berries and scar damage becomes noticeable as berries mature (Moreira et al., 2014). While such aesthetic damage resulting from thrips feeding may not be important for wine grapes, it may be significant for table grape quality. Cover cropping can have other effects on grape quality that were not measured here, such as chemical composition, aroma compounds, and soluble solids (Caspari et al., 1997; Xi et al., 2011; Silvestre et al., 2012; Zalamena et al., 2013).

4.3. Water use and cost

Buckwheat has been successfully grown as a summer cover crop in vineyards in Orange (New South Wales, Australia) (Simpson et al., 2011), Dresden (New York, USA) (English-Loeb et al., 2003), and Blenheim (New Zealand) (Berndt et al., 2002). Average monthly temperatures over summer are 5–11 °C lower and precipitation is up to 40.7–87.1 mm higher in these regions compared with the southern California (i.e., Temecula; Data for each area was sourced from: http://www.weather.com [Temecula and Dresden]; http://www.bom.gov.au [Orange] and http://www.metservice.com [Blenheim]) site used in this study. Growing a summer cover crop in southern California requires supplemental irrigation which may lead to significant costs in irrigation water and under drought conditions, water use penalties may be incurred. During the trial period in 2008, the cooperating winery was charged $10,019 for exceeding monthly water allocations. In 2007, there were no penalties charged during these months. It is unlikely that the water requirements of our trial caused the 2008 penalties since water usage by our trial only amounted to 0.7% of water consumption during March–August 2008. However, our trial consisted of small 30 m × 2 m row plots, and vineyard growers would likely sow cover crops along entire rows thereby implementing this strategy on a significantly larger scale throughout the vineyard. Increased plantings would make water penalties for sustaining cover crops under drought conditions more likely.

Providing nectar cover crops in every row to enhance fitness of beneficial insects may not be necessary since parasitoids and predators can move between floral refuges and the surrounding crop (Scarrett et al., 2008; Horton et al., 2009). Research has shown that *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae) dispersed 80 m from buckwheat refuges in broccoli fields in 4 days (Lavandero et al., 2005). Results from the current study showed that if buckwheat was sown in one row in every seven, water usage necessary to sustain a cover crop would have increased vineyard water consumption between March and August by 18%, which could have contributed to water allocation penalties. These estimated costs are for irrigation water only and does not include supplemental water (such as that applied via an ATV Tree Sprayer during this trial), cost of seed, and labor for cultivating soil and drilling seed. Buckwheat has been deployed in commercial vineyards in New Zealand at ten-row intervals with the distance between vine rows being 2 and 3 m (Scarrett et al., 2008). If buckwheat was sown one row in every eleven at the study site, total vineyard water consumption would have increased by 11% during March–August.

According to past (i.e., 2008 when this study was conducted) and current water bills (2015) for the experimental site, cost of water has increased by at least 263% since this study was conducted. Therefore, the current cost (i.e., 2015) of sustaining a buckwheat cover crop in southern California vineyards would have increased considerably since this study was conducted. Penalty charges to growers were terminated by the Rancho California Water Board in 2011 and instead a two-tiered rate structure (tier 1 = US $1.13 per HCF [28 cubic meters]; tier 2 = US$1.19 per HCP; 2015 water bill for the study site) was implemented (Rancho California Water Board, pers. comm.).

4.4. Cover crop establishment

This study demonstrated the difficulty of establishing a buckwheat cover crop in southern California due to issues with irrigation, poor seed quality, consumption of seeds and young plants by birds and rabbits, respectively, extreme summer temperatures, and severe damage to cover crop plants from tractors and vineyard workers during routine vineyard maintenance. Schonbeck et al. (1991) also found difficulty in establishing buckwheat during hot weather on dry soils in New England, USA.

Buckwheat was grown as a cover crop in southern California where high temperatures and almost zero rainfall during the summer requires substantial supplemental irrigation for successful establishment and growth. However, even with costly supplemental irrigation which increased pest populations and reduced berry quality, buckwheat establishment rates were poor. Investigating the use of drought tolerant plants which do not require significant supplemental irrigation over summer, such as the California poppy (*Eschscholzia californica* Cham. [Papaveraceae]) as a cover crop, may be viable in southern California vineyards if flowering phenology coincides with natural enemy activity and can enhance fitness. A cover crop mix of California poppy, buckwheat and dwarf cornflower (*Centaurea cyanus* L. [Asteraceae]) which has low summer water requirements enhanced populations of spiders, nabids, anthocorids, geocorids, parasitic hymenoptera, and adult coccinellids in hops grown in Los Lunas, New Mexico (Grasswitz and James, 2009). A xeric adapted blend of flowering plants may be a viable alternative to a buckwheat cover crop in areas with very low summer rainfall and high temperatures. Alternatively, maintenance of non-crop vegetation in the drip line may be another viable option for maintaining populations of beneficials assuming they do not promote pest populations and reduce grape quality (Norris, 1986; Silva et al., 2010).

4.5. Conclusion

A buckwheat cover crop grown over summer is not a viable pest management option for grape growers in southern California. This field work demonstrated the difficulty of establishing buckwheat due to poor seed quality and seed and seedling consumption by birds and rabbits. The increasing cost of irrigation water, especially under drought conditions, and the fact that buckwheat hosts the grape pathogen *X. fastidiosa* and its vector *H. vitripennis* (Irvin et al., 2014) collectively contribute to the infeasibility of conservation biological control in areas with low rainfall and high summer temperatures. Furthermore, supplemental irrigation to sustain the cover crop increased populations of pestiferous insects and reduced berry quality furthering decreasing the utility of this pest management strategy.

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