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Corresponding author:
Rachael Freeman Long;
Email: rflong@ucanr.edu

Established native hedgerows on field borders suppress weeds on farms

Rachael Freeman Long[1] and Justin Michael Valliere[2]

[1]Farm Advisor Emeritus, University of California Cooperative Extension, Woodland, CA, USA and [2]Assistant Professor of Cooperative Extension, Department of Plant Sciences, University of California, Davis, CA, USA

Abstract

Established hedgerows of native plants on the borders of crop fields provide a variety of ecosystem service benefits in agricultural landscapes. However, their influence on weed communities is not well understood, and there are concerns that hedgerows could contribute to weed infestations on farms. To address this research gap, we examined the role of established hedgerows of native California plants on weed abundance (weed numbers and cover) and weed species richness in field borders, and in adjacent crops, in large-scale, monocropping systems compared with conventionally managed field borders (i.e., no hedgerows). Across 20 farm sites in California's Central Valley, hedgerows on orchard crop borders reduced weed numbers by 66%, weed species richness by 59%, and weed cover by 74%. On annual field crop borders, hedgerows reduced weed numbers by 71%, weed species richness by 60%, and weed cover by 70%. In orchards, hedgerows also reduced weed intrusion into the adjacent crop interior, with significantly lower weed cover to the first tree row (area directly underneath the trees), weed species richness to the 10-m tree row, and weed numbers to the 10-m avenue (area between the tree rows). Yearly management practices and associated costs for weed control in established hedgerows were significantly less than for conventionally managed field borders. This study highlights the effectiveness of native hedgerows as a sustainable nature-based solution for reducing weed pressure and management inputs on farms.

Introduction

Established hedgerows of native plants on field borders increase biodiversity and ecosystem services in large-scale monocropping systems (Kremen 2020). This includes enhanced water-quality protection, carbon sequestration, and habitat for native bees and natural enemies, leading to better pollination and pest control services in adjacent crops (Chiartas et al. 2022; Heath and Long 2019; Kross et al. 2016; Long et al. 2010; Morandin et al. 2016; Webster et al. 2018). Ecological intensification from hedgerow planting practices does not take land out of production, as these narrow, linear strips of native perennial vegetation are planted on marginal areas alongside crops in field borders (also known as margins or edges), including roadsides, old fence lines, and terraces left over from land leveling.

The extent to which established hedgerows influence the weed community in agricultural systems is unclear. Diversification of farmlands has been shown to improve weed management (Sharma et al. 2021). However, the few studies examining the effect of field border habitat on weed communities has yielded mixed results. Wilkerson (2014) showed that hedgerows suppressed weeds, once plants were mature enough to shade and outcompete them, but suggested hedgerows could still function as conduits for weed invasion into adjacent crops. Sosnoskie et al. (2007) found no differences in weed communities in response to different field border habitat features in agricultural landscapes (i.e., fence row, forest, road ditch). However, Berquer et al. (2021) saw an increase in weed abundance (i.e., numbers of weeds) and weed species richness (i.e., the number of species) in field borders associated with nearby semi-natural meadows, showing that habitat landscape features can influence weed communities on farms.

Weeds spread in many ways, including short distances from field borders into adjacent crops, primarily by wind, water, animals, and equipment, where they can cause significant yield and crop-quality losses (Bourgeois et al. 2020; Oerke 2006; Thill and Mallory-Smith 1997). To control weeds on field borders, growers primarily rely on herbicides, disking, and mowing (Garbach and Long 2017). Some common weeds in farmlands are more problematic than others due to growth habit and herbicide resistance (Damalas and Koutroubas 2024). The extent to which hedgerows influence these weed communities in field borders and adjacent crops is unknown.

There is a perception among landholders that hedgerows increase weeds, leading to more time and costs to manage them (Garbach and Long 2017). This likely hampers the adoption of hedgerows on farms, often leaving field borders bare and ecologically unproductive. The objective of this study was to determine the role of established hedgerows of native California

Table 1. Farm sites with hedgerows assessed for weed abundance and weed species richness in the Sacramento Valley, California, by season, year, and crop[a].

Orchards				Field crops			
Summer 2015	Winter 2016	Summer 2016	Winter 2017	Summer 2015	Winter 2016	Summer 2016	Winter 2017
Walnut[1]	Walnut[2]	Walnut[1]	Walnut[1]	Tomato[6, b]	Wheat[b]	Sunflower[6, b]	Wheat
Walnut[2]	Almond[3]	Walnut[2]	Walnut[2]	Tomato[7]	Wheat	Sunflower[7]	Oats
Almond[3]	Almond[4]	Almond[4]	Almond[3]	Cucurbit[8]	Wheat[b]	Tomato[8]	Oats
Walnut	Almond	Almond[5]	Almond[5]	Tomato[9, b]	Oats[9, b]	Tomato	Wheat
Almond	—	—	—	—	—	—	—

[a]Matching superscript numbers with crops indicate the same farm sites.
[b]Annual crops farmed organically.

plants on weed abundance (measured as weed numbers and cover) and weed species richness in field borders and in adjacent crops in large-scale monocropping systems, compared with conventionally managed field borders (i.e., no hedgerows). Management practices and costs for weed control in field borders were also assessed to determine resources needed for managing established hedgerows on farms.

Materials and Methods

Study Sites

This study was conducted in Yolo, Solano, and Colusa counties in California's Sacramento Valley from 2015 to 2017. The study area is intensively farmed with nut tree crops (almond [*Prunus dulcis* (Mill.) D.A. Webb], walnut [*Juglans* spp.], and pistachio [*Pistacia vera* L.]) as well as annual rotational field crops (cereal grains, processing tomato [*Solanum lycopersicum* L.], rice [*Oryza sativa* L.], alfalfa [*Medicago sativa* L.], and hybrid seeds). The average farm size in the study area is 230 ha, with an agricultural market value of US$1.7 billion for the area ([USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service 2024). The region is characterized by irrigated crops, loam soils, and a Mediterranean climate with hot, dry summers and cool, wet winters.

Weed communities were assessed on 20 farms with well-established hedgerows planted on field borders by landowners between 1989 and 2009. Eight farm sites had nut crops (5 almond and 3 walnut) and 12 sites had annual, rotational field crops, including processing tomatoes and sunflower (*Helianthus annuus* L.) and cucurbit hybrid seed plantings during the summer, and cereal grains (wheat [*Triticum aestivum* L.] and oats [*Avena sativa* L.]) during the winter (Table 1). Each crop field was approximately 32 ha in size. One side of each field had a hedgerow of well-established native perennial shrubs and bunchgrasses that averaged 9-m wide by 550-m long (0.5 ha). The other three sides had field borders that were managed conventionally by tilling, mowing, and burning and with herbicides. The border on the opposite side of the hedgerow (about 350 m from the hedgerow) served as the control (i.e., conventional field border, no hedgerow), averaging 4-m wide by 550-m long (0.2 ha). Each farm field was generally surrounded on all four sides by other crop fields.

The plant species composition in the hedgerows varied somewhat, but all mainly contained the native woody perennials California buckwheat [*Eriogonum fasciculatum* Benth.], California lilac (*Ceanothus thyrsiflorus* Eschsch. var. *griseus* Trel.), California coffeeberry [*Frangula californica* (Eschsch.) A. Gray], coyote brush (*Baccharis pilularis* DC.), elderberry [*Sambucus nigra* L. ssp. *caerulea* (Raf.) Bolli], western redbud (*Cercis canadensis* L. var. *texensis* (S. Watson) M. Hopkins; syn: *Cercis occidentalis* Torr. ex A. Gray), and toyon (*Heteromeles arbutifolia* (Lindl.) M. Roem.). Field borders, with and without established hedgerows, were not irrigated.

All orchard nut crop farm sites were managed conventionally. Weeds were controlled by mowing and with pre- and postemergence herbicides, as described by Hasey et al. (2022) and Niederholzer et al. (2024). In the tree rows (the area directly underneath the trees), the orchard floor was intensively managed and kept clean and weed-free for good tree health. However, in the avenues, the area between the tree rows, there was often residual weedy vegetation, especially during the wintertime. All orchards were irrigated with subsurface drip or micro-sprinklers.

Three annual field crop farms (six fields) were managed organically (Table 1). All annual field crops were planted on 1.5-m-wide beds and direct seeded, except for tomatoes, which were transplanted. The cereal grains were planted in the fall and harvested in late spring or early summer and rainfed or irrigated with subsurface drip irrigation. Summer field crops were planted in the spring and harvested in mid- to late summer and subsurface drip irrigated, except for one tomato field that was furrow irrigated. Weeds were controlled by cultivation, and the use of pre- and postemergence herbicides in conventional crops, as described by Murray et al. (1997), Mathesius et al. (2016), Long et al. (2019), and Aegerter et al. (2023).

Data Collection

Weed abundance (i.e., weed numbers and cover) and weed species richness were assessed at the farm sites during the summer (June and July) and winter (January and February) from 2015 to 2017. Farms with hedgerows in our study area were limited; therefore, some sites were sampled in multiple seasons or years (Table 1).

For annual field crops, sampling transects were set at the following zones: border (hedgerow vs. conventional), crop edge (<9 m from the borders), and 10 m and 75 m distant from the borders into the crop interior (Figure 1). For orchards, the sampling design was the same as for field crops, but with three additional field zones to account for the more-intensive weed control practices in tree rows than avenues. Orchard zones included the following: border, crop edge (<9 m from the border), the first tree row (<10 m from the border), and the 10-m tree row, 10-m avenue, 75-m tree row, and 75-m avenue distant from the borders into the crop interior. The crop edge specifically refers to the transition area between the xeric border and the irrigated crop, which is open (no shading), with some water, nutrient, and weed control inputs, but not as much as for the crops. This area is narrow (<0.3-m wide) and

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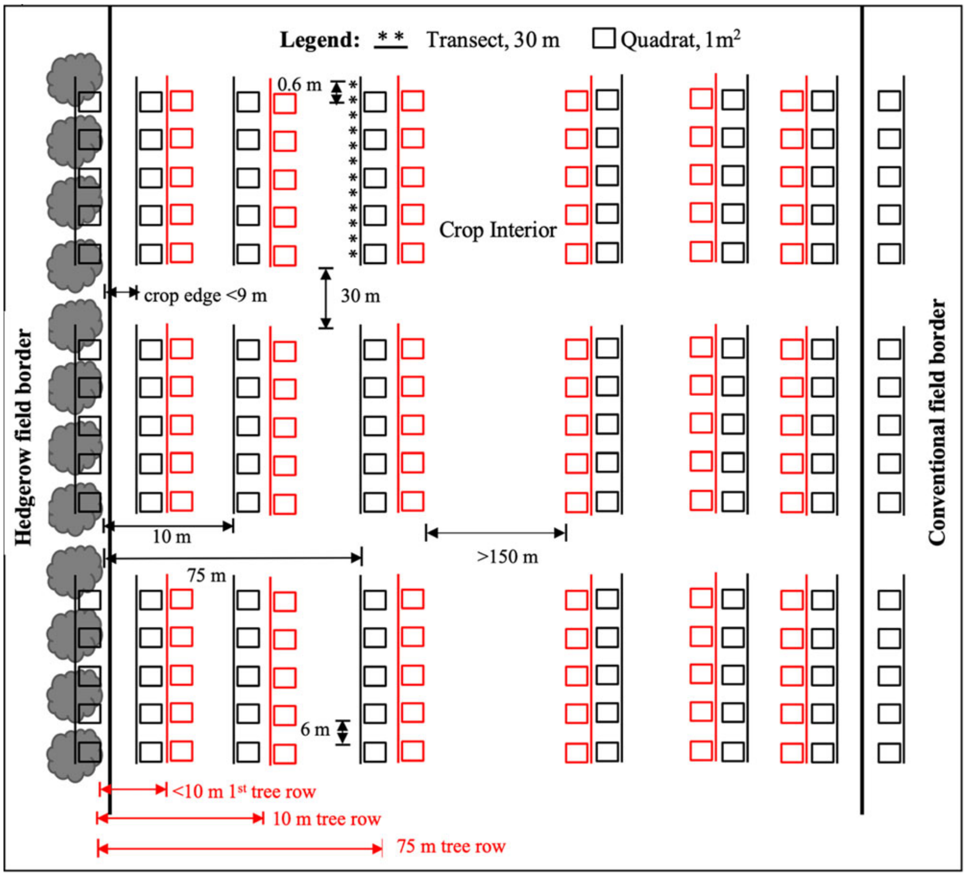

Figure 1. Diagram of sampling design using a combination of 1-m^2 quadrats (squares, 6-m spacing) to assess total weed cover (%) and point sampling (*, 0.6-m spacing) along 30-m transect lines for numbers of weeds and weed species richness on farms, with and without hedgerows on field borders, in the Sacramento Valley, California, 2015–2017. For orchards, unique field zones in the crop interior included the tree rows (area directly underneath the trees, in red), in addition to avenues (area between the tree rows), to account for the differences in orchard floor weed management.

was located 0 m to about 8 m distant from the field borders. For each crop field, there was more than 150 m between the hedgerow and conventional field border treatment zones.

At each field zone, there were three 30-m-long sample transect lines, each separated by 30 m (Figure 1). Point sampling was used to assess the numbers of weeds (i.e., weed counts per 30-m transect) and species richness of herbaceous vegetation on farms with and without hedgerows. For weed numbers and weed species richness, individual weeds were identified and recorded every 0.6 m along each 30-m transect line for each treatment zone. Two weeds sometimes found at the same point were both included in the total number of weeds per 30-m transect line. Percent weed cover was measured by visually assessing the proportion of ground occupied by each weed or native plant species in 1-m^2 quadrats, in increments of 5%, at 5 points (every 6-m) along each 30-m transect. For hedgerows, the sampling transects included the middle interior (centerline of the planting) as well as both outer edges.

Weed species identified in this study were primarily non-natives (Supplementary Table S1), with nomenclature and life cycle following Baldwin et al. (2012). Weeds of special concern, that is, those that are common, troublesome, and difficult to control due to their persistent and invasive nature, herbicide resistance, and impact on crop quality, were identified for each cropping system (Table 2) (Aegerter et al. 2016; Grant et al. 2020; Haviland et al. 2023; Long et al., 2019; Marsh et al. 2016; Miyao et al. 2023; Van Wychen 2022). The number of problematic weed species per 30-m transect was recorded in the hedgerow and conventionally managed field borders.

Statistical Analysis

All statistical analysis was performed using R v. 4.4.1 (R Core Team 2024). We analyzed three separate metrics of weed intensity, including the number of weeds and weed species richness (per transect) and percent cover (from quadrats). From the field-collected data, we calculated the total number of weeds observed per 30-m transect for each field zone across fields, as well as weed species richness per transect. To analyze weed numbers and species richness data, we applied generalized linear mixed models with field border type (i.e., hedgerow or conventionally managed field border) as the fixed effect, using the *glmer* function from the LME4 package. A Poisson distribution was specified for these models. For weed cover data, we calculated total percent weed cover across species for each quadrat and used linear mixed-effects models with the *lmer* function from the LME4 package to test for differences across the sides of fields with and without hedgerows. Separate mixed-effects models were run for each field zone in both orchards and field crops. Farm site location and sampling season were included as random effects in all models. Finally, we employed simple linear regression to assess the relationship between

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Table 2. Weed numbers for common and troublesome weeds in hedgerow and conventionally managed field borders, in annual field and orchard crops in the Sacramento Valley, California.

Problem weeds		Weed numbers per 30-m transect			
		Field crops[a]		Orchards[b]	
Common name	Scientific name	Hedgerow	Conventional	Hedgerow	Conventional
Annual bluegrass	*Poa annua* L.	—	—	0.2	3.8
Barnyardgrass	*Echinochloa* spp.	0	1.9	0	0.4
Cheeseweed	*Malva parviflora* L.	—	—	2.5	1.5
Chickweed	*Cerastium* spp.	0.1	0.5	—	—
Cocklebur	*Xanthium strumarium* L.	0	0.7	—	—
Field bindweed	*Convolvulus arvensis* L.	0.5	3.9	1.3	3.9
Fleabane, horseweed	*Erigeron* spp.	0	5.7	0.2	0.6
Groundsel	*Senecio vulgaris L.*	0	0.1	—	—
Johnsongrass	*Sorghum halepense* (L.) Pers.	—	—	0	0.6
Lambsquarters	*Chenopodium album* L.	0.1	2.2	—	—
Nutsedge	*Cyperus* spp.	0	1.0	0	0.2
Pigweeds	*Amaranthus* spp.	0	0.9	—	—
Purslane	*Portulaca oleracea* L.	0	0	0	0.3
Italian ryegrass	*Festuca perennis* (L.) Columbus & J.P. Sm.	1.6	3.8	0.4	2.0

[a]Problematic weeds in annual field crops.
[b]Problematic weeds in orchard nut crops.

native plant cover and weed cover within hedgerows across all farm sites.

Farm Budget Costs

Farmers and pest control operators shared their weed control practices in established hedgerow and conventionally managed field borders to enable assessment of management inputs and costs for each area. Mechanical practices used in field borders for weed control and associated costs in USD per hectare included tillage (ditcher-V US\$94 ha^{-1}, grading US\$30 ha^{-1}, disking US\$37 ha^{-1}), mowing US\$47 ha^{-1}, and burning US\$904 ha^{-1}, adjusted for once every 3 yr (J Murdock, UC Davis Agricultural and Resource Economics, Farm Cost and Returns Program).

Pre- and postemergence herbicides used included glyphosate, 2,4-D, rimsulfuron, indaziflam, glufosinate-ammonium, oxyfluorfen, penoxsulam, dithiopyr, flumioxazin, clethodim, triclopyr, and saflufenacil, individually or in mixtures, with surfactants (Supplementary Table S2). The herbicides were applied one to three times per year, at recommended labeled rates, with field sprayers (i.e., ATV-4WD with a tank and sprayer) at an application cost of US\$17 ha^{-1}. Herbicide retail costs, rates, and frequency of applications were used to calculate average pesticide costs on field borders in USD per hectare, along with kilograms of active ingredients used per hectare (kg ai/ae ha^{-1}).

There would be no assigned land costs (annual land rent) for hedgerows, as the land they are planted on is marginal and not available for crop production. There also would be no assigned water costs, as established hedgerows are generally not irrigated (Long and Anderson 2010). Occasionally hedgerows are pruned (US\$247 ha^{-1}) to keep plants from encroaching into adjacent crops and rights-of-way, generally once every 5 yr, but this was not considered a weed control practice.

Results and Discussion

Weed Abundance and Species Richness

Established hedgerows on field borders suppressed weed abundance (weed numbers and cover) and weed species richness compared with conventionally managed field borders. Specifically, in orchard crop borders, hedgerows reduced weed numbers by 66%, weed species richness by 59%, and weed cover by 74%. In annual field crop borders, hedgerows reduced weed numbers by 71%, weed species richness by 60%, and weed cover by 70% (Figure 2; Table 3). These data showcase the benefits of established hedgerows for helping to suppress weeds in field borders in large-scale monocropping systems.

Wilkerson (2014) demonstrated that the mechanism behind the reduced weed infestation in hedgerows was primarily due to shading and plant competition by the native plants. Our data likewise support this finding, as evidenced by the linear regressions showing a clear relationship where higher native plant cover corresponded to lower weed cover in field borders for both orchards and field crops (Figure 3). Weed seed predation by avian and non-avian wildlife using the hedgerows also likely helps suppress weeds in field border habitat on farms (Holmes and Froud-William 2005; Sellers et al. 2018).

For orchards, the reduction in weeds in field borders with hedgerows also led to less weed intrusion into the crop interior. Reduction in weed cover was significantly lower to the first tree row, weed species richness to the 10-m tree row, and weed numbers to the 10-m avenue in hedgerows compared with conventional field borders (Table 3; Figure 2). Beyond this distance, data for weed communities were highly variable (lots of outlier values for both treatments) indicating nonsignificance. These trends were not observed in annual field crops, likely due to frequent tillage practices masking treatment effects. Field crop ground is heavily worked, resulting in clean seedbeds for planting (Aegerter et al. 2023; Mathesius et al. 2016). By contrast, orchard ground is not worked once trees are planted (Hasey et al. 2022; Niederholzer et al. 2024), resulting in more residual weeds, allowing one to better observe weed communities and intrusion patterns from field borders. The slightly higher weed numbers (but not weed cover) found in annual field crop edges associated with hedgerows generally occurred on farms where hedgerows planted too close to crops likely interfered with weed control practices on outside rows. As a result, it is important to leave enough space between the hedgerow and the crop to allow for equipment access (i.e., sprayers, cultivators) for weed control. These open areas also help discourage bird predation of adjacent seedling crops (Long and Anderson 2010).

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Table 3. Results of statistical models evaluating the impact of hedgerows versus conventionally managed crop borders on total weed numbers and weed species richness (per 30-m transect), and total weed cover (%) across different field zones in orchards and field crops[a].

		Weed numbers per 30-m transect		Weed species richness per 30-m transect		Total weed cover (%)	
Farm type	Field zone	Estimate	P	Estimate	P	Estimate	P
Orchards	Border	−1.09 ± 0.04	<0.0001	−0.88 ± 0.11	<0.0001	−44.19 ± 2.91	<0.0001
	Crop edge	−0.44 ± 0.03	<0.0001	−0.62 ± 0.15	<0.0001	−14.55 ± 1.90	<0.0001
	First tree row	−1.01 ± 0.09	<0.0001	−1.26 ± 0.20	<0.0001	−3.02 ± 0.95	0.0015
	10-m tree row	−0.85 ± 0.10	<0.0001	−1.06 ± 0.23	<0.0001	1.14 ± 0.97	0.2490
	10-m avenue	−0.17 ± 0.03	<0.0001	−0.17 ± 0.09	0.0567	−3.89 ± 2.19	0.0757
	75-m tree row	−0.32 ± 0.09	0.0011	−0.60 ± 0.23	0.0077	4.44 ± 5.38	0.4330
	75-m avenue	0.01 ± 0.03	0.9020	0.07 ± 0.09	0.4480	−1.08 ± 1.96	0.5820
Field crops	Border	−1.22 ± 0.04	<0.0001	−0.98 ± 0.11	<0.0001	−45.04 ± 2.21	<0.0001
	Crop edge	0.15 ± 0.04	0.0004	−0.18 ± 0.12	0.1270	−0.84 ± 1.70	0.6206
	10 m	−0.14 ± 0.09	0.4510	−0.14 ± 0.18	0.4510	−0.46 ± 0.38	0.2305
	75 m	0.06 ± 0.12	0.6180	−0.20 ± 0.28	0.4885	−0.10 ± 0.36	0.7718

[a]Model estimates (± SE) and P-values are provided from generalized linear mixed models for weed numbers and weed species richness and from linear mixed-effects models for total weed cover. Model estimates reported represent the log-transformed expected change in weed parameters between the two groups (e.g., native hedgerows vs. conventional fields).

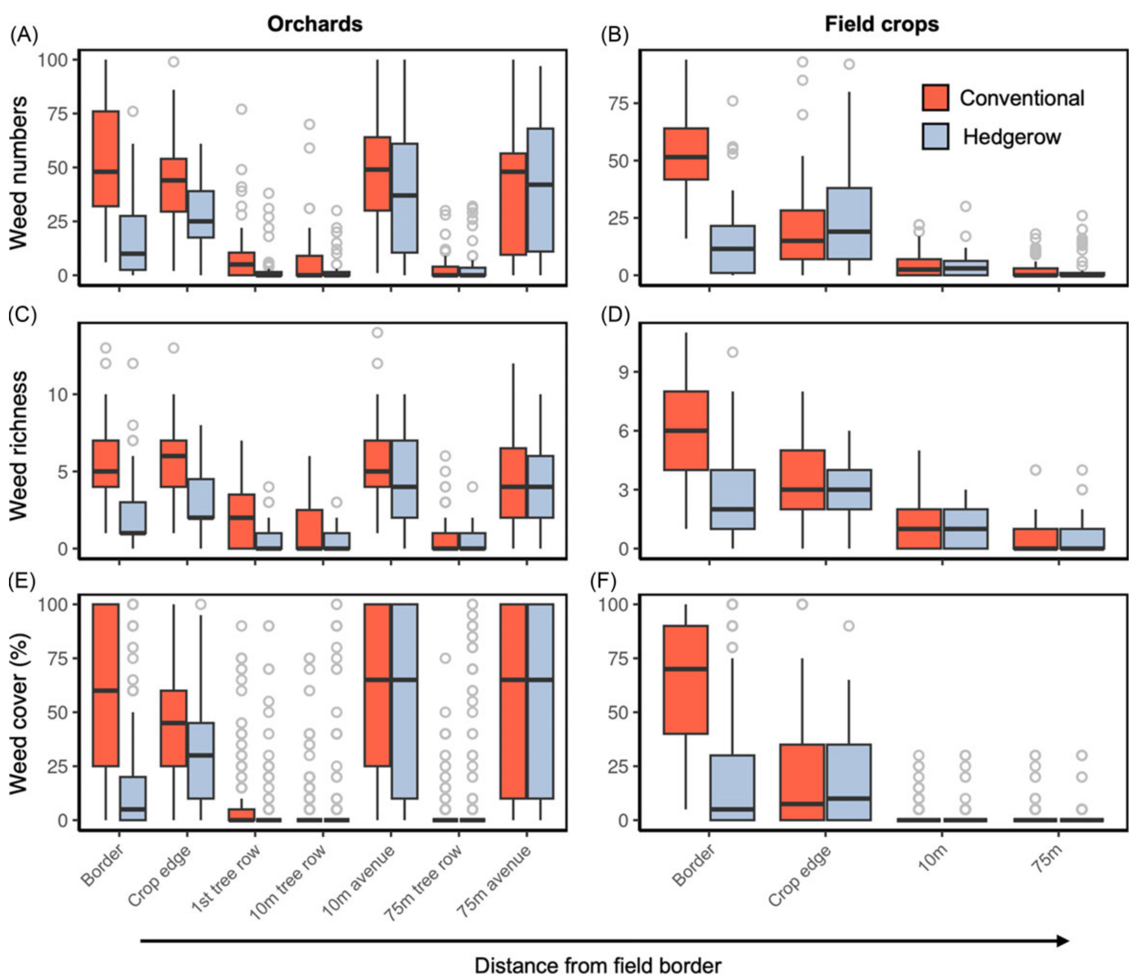

Figure 2. Box plots depicting weed numbers per 30-m transect (A and B), weed species richness per 30-m transect (C and D), and total weed cover (%) per 1 m^2 (E and F) within orchards and annual field crops, comparing hedgerows with conventionally managed field borders. Data are presented across multiple field zones at increasing distances into the crop interior from the field borders, encompassing all farms and sampling seasons.

Conventional field borders were often weedy at our study sites, even though they were always managed for weed control. This may have occurred from resistance and selective weed pressure from herbicide use, leaving residual weeds in the field borders (Damalas and Koutroubas 2024). Tillage can also spread weeds and open up areas, favoring weed intrusion (Wright et al. 2011). However, probably the biggest driver of weeds in field borders is that these areas have little economic value, so they are minimally managed. In our study, weed control on field borders often occurred when weeds were controlled in adjacent crops, but other times not until crop

Table 4. Weed management practices in established hedgerow and conventionally managed field borders, number of sites using the practice, average weed control costs, and average herbicide use in the Sacramento Valley, California, 2024.

	Number of sites using practice[a]		Average cost ha^{-1}[b] US$		Average herbicide use kg ai/ae ha^{-1}	
Field border management practice	Hedgerow	Conventional	Hedgerow	Conventional	Hedgerow	Conventional
Herbicides	0	9	0	164	0	2.78
Herbicides+mow	0	3	0	48	0	0.64
No management	10	0	0	0	0	0
Tillage	0	4	0	28	0	0
Mow	8	1	38	23	0	0
Mow+tillage	1	2	6	4	0	0
Burn[c]	1	0	9	0	0	0
Burn+tillage	0	1	0	17	0	0

[a]There were 20 sites and 14 grower participants.
[b]Prepared in collaboration with Jeremy Murdock, UC Davis Agricultural and Resource Economics, Farm Cost and Returns Program. Herbicides include application costs.
[c]Burning costs adjusted for once every 3 yr.

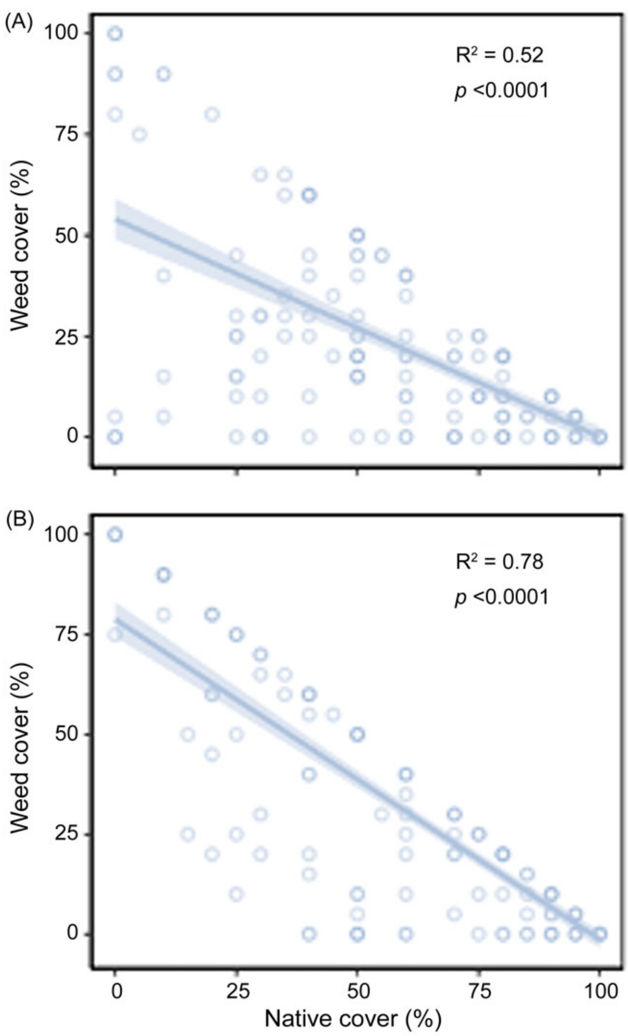

Figure 3. Linear regressions illustrating the relationship between total native plant cover (%) and total weed cover (%) per 1 m^2 within hedgerows for both orchards (A) and field crops (B) across all farms and sampling periods. Regression lines are depicted with their corresponding 95% confidence bands.

harvest, particularly if special equipment had to be brought in, like sidearm mowers for ditches, allowing weeds to thrive in these areas.

Problematic Weeds

Weed numbers per 30-m transect for common and troublesome weeds across all farms and sampling periods were lower in the hedgerows than conventionally managed field borders for every weed species except cheeseweed (*Malva parviflora* L.) in orchards (Table 2). The higher number of *M. parviflora* was primarily driven by one site that had high levels of this weed along the hedgerow edge. *Malva parviflora* thrives in areas without shading, readily spreads by seed, has a large taproot, and is resistant to many herbicides, making it difficult to control (Wilen 2006). Individual site observations show the importance of watching for troublesome weeds to keep them from establishing and infesting crops, regardless of field border habitat.

Budget Costs

Weed management was always more intensive in conventional field borders than in hedgerows at all 20 farm sites (Table 4). For hedgerows, half the sites were mechanically weeded every year, mostly by mowing along outside edges where weeds can persist, but the rest of the sites were not weeded, nor were herbicides used. For conventional field borders, weeds were controlled every year, either mechanically (40% of sites) or with herbicides (60% of sites). An average of 3.42 kg ai/ae ha^{-1} of herbicides was used per year on the conventional field borders across the farm sites.

The reduced weed control practices in hedgerows led to lower weed management costs compared with conventional field borders. Overall, across all sites, the average yearly cost for weed control in established hedgerows was 80% less than for conventional field borders (Table 4). When establishing hedgerows, weed control is the most time-consuming and costly practice (Long and Anderson 2010). However, our results show that once established, hedgerows that have a greater density and cover of native plants will yield greater weed suppression, helping to reduce the need for herbicides and other weed control practices in field borders, leading to lower yearly management costs.

With the demand for more and better food and more sustainable practices driven by the growth of incomes among the world's poor, there is a growing need for farming practices that leverage nature-based solutions to reduce external inputs onto farms and increase farm resilience. Our study shows that hedgerows can help fill this need by enhancing weed control in agricultural landscapes, while at the same time, bringing other

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ecosystem benefits (i.e., pollination and pest control services). Incentives and support for habitat restoration on farms, including hedgerows, are increasingly available through the U.S. Department of Agriculture's Environmental Quality Incentives Program (USDA-NRCS 2024), as well as the California Department of Food and Agriculture Healthy Soils and Pollinator Habitat programs (CDFA-OEFI 2024). This technical and financial support, along with information showcasing the benefits of hedgerows on farms, will help facilitate the adoption of hedgerows on farms for a healthier world.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/wsc.2025.2

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