Impacts of mulched cover crops on weed cover and composition at two California vineyards.

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Abstract:

We studied the effects of several mulched cover crop systems to change and suppress weeds in the vine rows at two rainfed, northern California vineyards. Weed suppression under these mulched cover crop systems were comparable and sometimes better than those under a conventional tillage and herbicide system. Cover crop productivity and its associated suppressive potential matched weed productivity and seemed to be determined primarily by location and then by precipitation patterns within each of the vineyards. At the Buena Vista site in Sonoma County biomass from mulched cover crops averaged 936 g m^{-2} by the last year whereas at the Frei Brothers site in Napa County mulch biomass averaged 427 g m^{-2}. Weed suppression was linked to light interception by the mulch cover for most weed species. Subclover (*Trifolium subterranean*) planted directly in the vine row had the most significant impact on weed suppression and species richness changes at the Frei Brothers location. The increased dominance of the perennial, *Convolvulus arvensis*, and reduction of certain annual species was indicative of species compositional changes in all treatments.

Key words: cover crop, weed management, vineyards, mulch, species richness

Introduction:

Weeds in vineyards can result in significant reduction in vine growth and grape yields (Hembree and Lanini, 2006). These losses are the result of competition for water, nutrients, and under some circumstances light. Conventional methods used in California include a complete no tillage system that relies on herbicide applications in the vine rows and the area between them (middles) or a combination of herbicide strip application in the vine row and mowing or disking of the middles. Concern about the potential consequences of not using herbicides to suppress weeds has limited the adoption of organic methods such as cover cropping and mulching (Bond and Grundy, 2001).

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Cover crops have been utilized to enhance soil fertility and to improve soil structure for moisture retention (Fageria et al., 2005; Hartwig and Ammon, 2002; Elmore et al., 1997). Cover crops and their mulch residues are also utilized to manage weeds because they reduce direct costs associated with herbicide applications and the indirect costs associated with vine and environmental damage. A live cover crop cannot be maintained throughout the year without supplemental irrigation in most California vineyards (Wolpert et al., 1993). In these situations the level of efficacy of mowed or desiccated mulch seems to depend most on soil coverage and its effect on light interception rather than on the effects of altered moisture or temperature regimes, allelopathy, or mechanical impedance (Liebman and Davis, 2000; Teasdale, 1993; Teasdale and Mohler, 1993). The benefits of cover crops and mulching have been documented but few growers have used the mown vegetation as mulch in the vine row. Consequently, there has been a call to further document the response of various weed flora in different regions to this type of mulching system (Dastgheib and Framption, 2000).

Teasdale et al. (1991) estimated that about half the bare ground must be covered for any reduction in weed density. From about 50% ground cover and up weed suppression is roughly an exponential function of mulch cover. Unfortunately, depending on environmental conditions, mulches can break down rapidly resulting in insufficient soil coverage thus allowing weed seed germination and subsequent growth (Teasdale and Mohler, 1993; Facelli and Pickett, 1991a). Cover crop mulch systems which utilize grass species have been found to provide similar coverage and light interception to those utilizing legume species but differ in their rates of breakdown (Teasdale and Mohler, 1993).

Species compositional changes have been observed for different weed management systems with grasses predominating in no-tillage systems and broadleaf species in conventional tillage systems (Teasdale et al., 1991; Wrucke and Arnold, 1985; Ogg and Dawson, 1984; Pollard and Cussans, 1981). Species numbers can be significantly reduced in no-till, herbicide systems with grasses and perennials predominating (Zaragoza et al., 1989). Some weed species show no unique association with management practices performing equally well in all systems (Zaragoza et al., 1989; Wrucke and Arnold, 1985). Increases and decreases in species richness have been observed under conditions where plant biomass covers the soil depending on the species composition and patchiness of the plant residue (Facelli and Pickett, 1991a and 1991b).

Our objectives with this study were to (1) compare overall vine row weed suppression for mulched cover crop systems and conventional weed management methods, (2) assess shifts of weed species composition that occur in response to several years of mulch and conventional weed management regimes, and (3) compare two commercial vineyards in the Napa Valley which differ in soil type for weed management and species shift.

Materials and Methods:

Studies were conducted at two commercial vineyards in the Napa/Sonoma region beginning in the fall of 1991. The first study site was at the Buena Vista (BV) vineyards in southeastern Sonoma county (Fine loamy, mixed, Thermic Ultric Palexerales) and the second study was at the Frei Brothers (FB) ranch in northern Sonoma County (Clayey, mixed, Thermic Typic Haloxerults). The experiment was a randomized complete block design with four replications. Buena Vista site had been a dairy pasture prior to planting of the vines. The main vine row management treatments were three types of mulched covercrops, mulched resident vegetation, and a conventional method. At Buena Vista, the conventional method was an herbicide system in the vine row and disked between the rows in the spring, while at Ffrei Brothers, a cultivation system in the vine row and between the rows was used. A reseeding subterranean clover (*Trifolium subterranean* mixture of inoculated varieties: Junee, Trikala, and Koala planted at 75-85 kg/ha) treatment was established as a subplot in the vine row of the three cover crop treatments at both locations. However, because it never became established at Buena Vista it was eliminated from the design at that location. Main plot size was four vine rows 100m in length. The area assessed was the central meter of a 3m strip directly under the vine rows. Subplot size was half the length of the mainplots.

The cover crop treatments at both locations consisted of *Avena sativa* var. 'Ogle' (planted at 70 kg/ha at FB and 101 at BV), *Vicia villosa* 'purple vetch' (planted at 59 kg/ha at FB and 94 at BV), and a 50:50 oat-vetch combination (planted at 102 kg/ha at FB and 112 kg/ha at BV). These treatments were established into cultivated soil in the 2.7 m (FB) and 2 m (BV) strips (middles) between the vine rows each October, beginning in 1991 with a precision drill planter. In April of each year, these strips were mowed with a modified flail mower so that the mowed vegetation was deposited into the vine row by a rear-mounted conveyor (Trimax Mulchmasta with Sidewinder conveyor unit[5],). The result was a dense, concentrated mulch layer directly underneath the vines. A resident vegetation plot was also established at each location as a control plot. In these plots, resident vegetation was allowed to grow in the strip middles during the winter and early spring, and mulched at the same time that the sowed cover crops were mulched. Both sites produced wine grapes commercially, and therefore would not allow for plots that were not managed in some way.

The herbicide treatment in 1991 at Buena Vista consisted a combination mixture of oryzalin (4-(dipropylamino)-3,5-dinitrobenxenesulfonamide) at 4.4 kg/ha, oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene] at 1.6 kg/ha, and glyphosate (*N*-(phosphonomethyl)glycine) at 0.8 kg/ha. This mixture was also applied on 1 April 1992 and 5 April 1993, and 30 January 1994 in the vine rows except that simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine) at 2.2 kg/ha was substituted for the oxyfluorfen. An in-row cultivator (Kimco Mfg.[6]) was utilized for the cultivation treatment at Frei Brothers. It had a

[5] Trimax, Pacific Mowers Ltd. 70 Maleme St. PO Box 2150, Taruranga, NZ

[6] Kimko Mfg., 9200 West Barstow, Fresno, CA 93722 USA

modified swing arm mechanism which allowed it to move around vine trunks without damaging them. Cultivation occurred at about the same time that the other treatments were mulched in April of each year. Both locations were primarily rainfed systems. An occasional irrigation was made during late summer months at Frei Brothers using precision drip emitters which were placed directly next to the vines.

Vegetation cover was assessed in January, March, June, and August of 1992 through 1994 except no assessment was done January 1992. Four 30m transects were laid along the center of the vine row. Readings were taken at 30 cm intervals along the transect. Multiple interceptions per interval from the top of the canopy to the ground were recorded otherwise understory species would be significantly underestimated. Four $0.25m^2$ quadrats were laid out randomly along the vine row in each plot to better quantify rare species cover (Krebs, 1999). All species that were observed in transects and quadrats were identified and recorded. Species richness was estimated by the jackknife method to assess change in richness over the course of the experiment at the March and August assessments (Krebs, 1999). Within each cover crop and resident plot, four randomly placed $0.25\ m^2$ quadrats were clipped and assessed for dry biomass in April of 1994 to estimate mulch biomass that would be placed in the vine row by the flail mower.

Measurements of photosynthetically active radiation (PAR, $\mu mol\ m^{-2}\ s^{-1}$) at soil level were taken at the same time that the vegetation assessments were made. A PAR reading was taken at the mulch surface directly above the site where the soil level PAR measurement was taken. At least ten measurements were taken per plot with an 80cm Sunfleck Ceptometer (Decagon Devices Inc.[7]). The readings were averaged, and expressed as a percent of radiation incident at the top of the mulch layer.

Precipitation records for the period spanning the duration of the project were downloaded from the University of California Integrated Pest Management Program homepage (http://www.ipm.ucdavis.edu/). The data were collected daily at automated California Irrigation Management Information System (CIMIS) weather stations which were situated within ten miles of the experimental sites.

The primary data were log transformed after adding a constant to meet assumptions of analysis of variance (Berry, 1987). The constant was chosen by simultaneously minimizing the absolute values of the sum of skewness and kurtosis. These primary data included the transect assessments of total weed cover and dominant species cover for each assessment date, year, and location. The dominant species were those with the three to five highest ranked percent cover at a given location and date.

The analyses were performed using the REPEATED statement available with the GLM procedure in SAS (SAS for Windows, 2002-2003). Multiple comparisons were performed by

[7] Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163 USA

defining the desired contrasts in the M-matrix, and utilizing the MANOVA statement (Littell et al., 1991). Multiple comparisons of main treatment and subtreatment effects that were summed over a repeated factor were accomplished by computing a minimum significant difference based on Tukey's Honestly Significant Difference (α=0.05).

To exaggerate the distinctiveness of samples with rare species, Canonical Correspondence Analysis (CCA) was used to arrange all weed species along the measured environmental gradients in CANOCO (ter Braak and Smilauer, 2002). This analysis was used not to elucidate community structure in general, rather only whether some portion of community structure was more strongly related to the treatments and measured variables. The quantitative environmental variables were year, mulch cover, total precipitation for the three months prior to each assessment date, and a cumulative precipitation beginning in November of each year through October of the subsequent year. The nominal environmental variables were the main treatments at both locations and subtreatment at Frei Brothers. A CCA diagram was generated and interpreted using species scores with biplot scaling and environmental biplots scores of the quantitative variables and centroid scores of the nominal variables for the first two CCA axes (Leps and Smilauer, 2003).

Results:

The 1992 year growing season was typical for Napa and Sonoma counties with a total cumulative rainfall of 41.9 cm at the Buena Vista site and 54.1 cm at the Frei Brothers site. For 1993 and 1994 those totals were 51.1 cm and 24.6 cm at Buena Vista, respectively, and 101.1 cm and 39.6 cm at Frei Brothers, respectively. At both locations, most of the precipitation fell during the months of January, February, and March except at the Frei Brothers location in 1994 when over 10 cm fell in May after the cover crops had been mulched into the vine rows. In summary, precipitation patterns were typical in 1992, unusually high in 1993, and low in 1994 given the late timing of the rainfall. This rainfall pattern was reflected in the overall productivity of the weeds and the cover crops.

The relationship of weed and mulch cover was best characterized by an exponential decay function at BV with a coefficient of determination of 0.81 (Figure 1). Weeds were suppressed to about 30% cover or less when mulch levels exceeded about 20% cover. Weed cover increased dramatically when mulch cover was less than 20%. At Frei Brothers, the weed cover was best represented as a negative linear function of mulch cover with a coefficient of determination of 0.74 (Figure 1). Subclover cover was highest in 1993 when it exceeded 40% cover in the subplots where it was sowed in 1992. However, it had a significant impact on weeds even though its cover was very low in 1994. Therefore, subplots sowed with subclover in 1992 were not included in the regression. Photosynthetically active radiation attenuation appeared to be a linear function of percent mulch cover at both locations including the subclover subplots (Figure 1). The March assessment date in 1994 represents the expected control after three years of mulching. It was the time just prior to mulching for that year when the mulch cover persisting from the previous years was at its lowest and weed pressure due to growth in the current year was at its highest. At both locations, *C. arvensis* cover was not included in the analysis because the vine-like growth habit of this species was entirely different from any of the other species. These relationships were typical of other assessment dates (data not shown).

Mulch cover that had persisted in the mulched treatments from the previous season before application in 1994 was higher at FB, which averaged 84% cover compared with BV at 40.4% (Table 1). Mulch biomass applied to the vine row at BV in 1994 was in excess of 1000 g m^{-2} in the oat and oat-vetch cover crop treatments and exceeded 500 g m^{-2} in the vetch and resident treatments (Table 1). Mulch production at FB in 1994 was less ranging from 296 g m^{-2} in the resident to 513 g m^{-2} in the oat-vetch treatment. Mulch application to the vine rows was similar at both locations with an average 89% cover in the vine row. The subterranean clover failed to establish at BV but produced over 40% cover in the subplots that were sown with it in 1992 at FB (Table 2). The subclover provided no cover during the late summer months after it had set seed all three years and performed poorly all of 1994.

The species composition at both locations was typical of north coast vineyards with at least some weed growth occurring year round (Table 3). Total weed cover was significantly higher at Buena Vista (34.4%) than at Frei Brothers (26.1%) across all treatments and assessment dates (Table 4). Yearly average weed cover combined over locations, assessment dates, and treatments was significantly higher for 1993 than 1992 or 1994 (Table 4). However, cover at Buena Vista was not significantly different across years. Of the four mulched treatments, total weed cover in the resident treatment was significantly higher than in the other three at Frei Brothers while at Buena Vista, total weed cover was highest in the vetch treatment (Table 4). Buena Vista had significantly higher weed cover for all assessment dates except for the March assessment in 1992 and 1993 and August of 1993 (Table 5). Monthly average total weed cover combined over locations, years, and treatments was significantly higher before mulching at the March assessment (41.0%) than after mulching at the June (27.7%) or August (21.9%) assessments. At both locations, total cover in June and August were not significantly different from each other (Table 5). However, in 1994 the highest weed cover of the year occurred in June. This was probably due to the late timing of the rainfall during that year.

At Buena Vista, species numbers fluctuated greatly in the herbicide plots but the vetch and resident treatments consistently possessed the greatest number of observed weed species (Figure 2). The large fluctuation can be seen in the change in species richness over the course of the experiment from 1992 to 1994 at the March and August assessment dates where most treatments experienced an increase in species richness (Figure 3). The exceptions were the vetch and herbicide treatments which experienced significant decreases in species richness over the course of the experiment at the March assessment. In general, species richness increased over the course of the experiment in the mulched treatments by the August assessment. By the end of the experiment in August 1994, the herbicide treatment had a significantly lower species richness (7.8±1.5 species) relative to the other treatments which were not significantly different from each other (averaging 12.2 ±1.5 species). Species that were dominant in the January assessment tended to remain dominant at the March assessment. Species that were dominant in August were those surviving from June because there was very little rainfall between these two months. Total weed cover was significantly higher in the vetch treatment of all treatments across all assessment dates (Table 4). The dominant weeds before mulching each year at the March assessment were *Brassica nigra*, *Malva parviflora*, and *Sonchus oleraceus* which tended to grow best in the vetch treatments (Table 6). Above-ground cover for all species was eliminated from the herbicide plots following the winter1994 application.

Toward the end of the growing season in August, there were no significant differences among treatments for total weed cover averaged across all years (Table 6). At the end of the experiment in August 1994, the herbicide treatment had significantly lower total weed cover than the resident treatments and neither of these was significantly different from the cover crop treatments. There was a significant reduction in total weed cover over the course of the experiment averaged across all treatments. The late season dominance of *M. parviflora* in early years gave way to *Convolvulus arvensis* especially by 1994. Unlike *M. parviflora,* however, *C. arvensis* was ubiquitous in all treatments, and tended to be more successful in the herbicide treatment. As *M. parviflora* and *Picris echlioides* declined during the years, *S. oleraceus* and *Lactuca serriola* cover remained consistent but moderately low throughout the years.

Species richness decreased over the course of the experiment at the March assessment dates at FB except in the oat/vetch treatment (Figure 3). Species richness increased significantly during the experiment at the August assessment in all treatments except vetch. At the end of the experiment in August 1994, the cultivated treatment had a significantly higher species richness with 29.8 (±4.5) species relative to all other treatments which were not significantly different from each other averaging 13.4 (±1.8) species. Total weed cover at FB was consistently highest in the cultivated, and sometimes, resident treatments (Table 5 and 7). The dominant species at FB were *Erodium* spp. and *Poa annua* in the winter/spring and a mixture of *Sonchus oleraceus*, *C. arvensis*, *Conyza canadensis*, *L. serriola*, and *Epilobium brachycarpum* in the late summer (Table 7). The *Erodium* spp. displaced *Stellaria media* as the dominant winter weed by 1994. The highest cover that was observed for the *Erodium* spp. was in the resident and cultivated treatments. *Poa annua* was the dominant grass prior to mulching each year especially in the resident and cultivated plots. Like Buena Vista, there were no significant differences among treatments by the end of the growing season each year in August. Overall weed cover decreased significantly by the end of the experiment across all treatments (Table 7). *Sonchus oleraceus* and *E. brachycarpum* were the two most dominant weed species by August each year but their cover decreased significantly by 1994. Meanwhile C. *canadensis* cover increased significantly over time by 1994.

The most significant weed suppression effect at Frei Brothers was observed within the subterranean clover subtreatments (Table 8). The subterranean clover effect at FB was significant at most assessment dates whether it was actively growing or not. There were no significant subclover by cover crop treatment interactions, however, there were several interactions that involved subclover and year (Table 8). As with all annual vegetation, subterranean clover growth was most significant in the spring of 1993 (Table 2). As occurred in the main treatments, overall weed cover decreased significantly in the course of the experiment averaged across the subclover effect (Table 8). Also, the *Erodium* spp. displaced *S. media* as the dominant winter weed species. Species numbers were significantly reduced at many of the assessment dates in the subplots containing subclover (Figure 2). Species richness was significantly reduced by the end of the experiment in August 1994 from 40.8 (±1.1) where subclover was absent to 17.6 (±0.6) where it had grown. There were no consistent patterns for changes in species richness over the course of the experiment attributable to the subclover effect (Figure 4). Even though *S. media* was not present by 1994, its disappearance seems to have little to do with the subterranean clover effect because its cover was not different with or without subterranean clover. *Convolvulus arvensis* appeared to be unaffected by subterranean clover presence showing the same ubiquity that occurred in the main treatments at FB (Table 8).

The Canonical correspondence analysis (CCA) diagram for the March assessment date was representative of weed preferences and associations prior to mulching each year while the August assessment date was representative of the end of the growing season each year. The first two axes of the CCA diagrams for Buena Vista explained 61% of the variance in the weighted averages of all weed species along the environmental variables averaged over all assessment dates (Figure 5). At Frei Brothers the CCA diagrams explained an average 59% and 63% for the main treatment and subtreatments, respectively (Figures 5 and 6).

Mulch cover and year had the longest arrows and thus were more correlated with the CCA axes and strongly related to community structure prior to mulching each year in March (Figure 5). The year and rain factors were nearly uncorrelated (r=-0.09) at this date based on their near perpendicular orientation. Based on the ordering of the weighted average species scores (i.e. perpendicular projection onto the environmental arrows or their extensions), the increased abundance of *C. arvensis* (species #13 in Figure 5) over the course of the experiment can be seen by its top ranking along the year arrow in March (Figure 5). However, the relative total abundance of this species is lowest in the herbicide treatment among all treatments based on its distance from each treatment centroid in the biplot. The opposite was true of *S. media* (#35) where it ranked last on the year arrow. *Bromus rigidus* (#7) increased over the years and was associated with drier conditions based on its second to last ranking along the rain arrow. The *Erodium* spp. (#15 and 16) and the thistles, *Carduus pycnocephalus* (#9) and *Silybum marianum* (#32), ranked high on the mulch arrow while *S. oleraceus* (#34), *M. parviflora* (#24), *S. media* (#35), and *A. menziesis* (#1) ranked low (Figure 5). The short distances in the biplot between *S.*

marianum (#32), *E. moschatum* (#15), and *C. pycnocephalus* (#9) approximates the Chi square distance between their distributions and was indicative of their co-occurrence in the samples.

The effect of time (year) seemed to be most strongly correlated with community structure variation in the CCA diagram by the end of the growing season in August (Figure 5). The top ranking of *Conyza canadensis* (#14) was indicative of its increase over the course of the experiment. Most species scores are furthest away from the herbicide centroid of all the treatment centroids indicating their low abundances in that treatment.

As with Buena Vista, the rain and year variables were longest and thus most related to community structure at Frei Brothers at the March and August assessment dates (Figure 6). The proximity of the resident and cultivated centroids was indicative of their similar species composition and abundances. The cultivated and resident centroids ranked last and second to last, respectively, on the mulch arrow of the other treatments indicating their low mulch levels and similar effect on species composition. At the March assessment date, many species increased over the years and apparently preferred drier conditions based on the lengths and opposing directions of the rain and year arrows in the CCA diagram. Most species scores were furthest from the cultivated treatment centroid indicating their low relative total abundances in that treatment relative to the other treatments. *Erodium botrys* (#19 in Figure 6) and *Spergula arvensis* (#51) had the shortest distance to and thus their highest relative total abundances in the resident treatment centroid compared with the other treatments. The high ranking of *C. arvensis* (#13), *B. rigidus* (#5), and *Conyza canadensis (*#15) along the year arrow was indicative of their increases in later years. The low ranking of *S. media* (#52), *Lupinus wyethii* (#33), and *Calandrinia ciliate* (#6) on the year arrow was indicative of their decrease. Year, mulch, cumulative rain and rain arrows were the longest for the August assessment date (Figure 6). Many species appeared during later years but the ones that ranked highest along the year arrow were *Rhus trilobata* (#41), *Bromus diandrus* (#5), and *Lithocarpus echinoids* (#31). *Rumex acetosella* (#44) ranked highest on the mulch arrow relative to the other species while *E. botrys* (#19), *S. media* (#52) and *P. annua* (#37) seemed to prefer lower mulch levels.

The ANOVA revealed significant impacts on weed cover when subclover was sowed at the beginning of the experiment. The CCA revealed that the subclover effect may not have affected species composition based on the relatively small subclover arrows (Figure 7). As with the other CCA biplots, rain and year variables seemed more related to species composition. Most species in the CCA biplots were further from the subtreatment centroid than any of the other treatment centroids indicating the low relative total abundances of most species in the subclover plots. *Erodium* spp. (#18 and 19 in Figure 7) cover was found to decline significantly in the ANOVA over the years and was reflected in the CCA by their low ranks on the year arrow at the March assessment date. Species such as *C. bonariensis* (#14), *Rumex crispus* (#45), and *Capsella bursa-pastoris* (#8), however, ranked high on the year, rain and mulch arrows demonstrating their appearance in later years and preference for high rain and mulch levels.

Most species showed a preference for low subclover levels with the exception of *Lupinus wyethii* (#33) and *Calandrina ciliate* (#6).

At the August assessment dates, the mulch, year, and subtreatment arrows were the most correlated with the CCA axes but species scores were distributed such that year appeared to maximize species spread (Figure 7). The analysis shows that the appearance of *Rumex acetosella* (#44) and *B. diandrus* (#5) corresponded to later years and that *P. echliodes* (#36) and *A. fatua* (#2) ranked high along the mulch arrow and thus had high response optima at higher mulch levels compared to other species. Species scores for dominant species such as *S. oleraceus* (#49) and *L. serriola* (#27) were placed close to the center indicating that the variation in their cover was not well explained in these two dimensions or by these environmental variables. Notably, the subclover arrow was not very long in this projection even though its significance was clear in the ANOVA most likely indicating its suppressive impacts on all weeds rather than select species.

Discussion:

The variation in precipitation among years explained much of the variation of weed cover and cover crop performance. Higher precipitation resulted in higher weed performance but also in higher cover crop performance which lead to greater mulch rates. The higher mulch rates resulted in more effective weed control following mulch application. Lower precipitation resulted in the opposite effect. Thus the cover cropping management system appears to be a self-regulating system: its weed suppressive capacities will tend to be highly correlated with the potential severity of the weed problem.

Just as precipitation may explain vegetative performance, so too might soil type explain the observed differences between sites. At Frei Brothers, the soil type had a higher bulk density than at Buena Vista where the soil contained a higher fraction of clay. Additionally, a dairy farm occupied the BV site prior to its conversion to vineyard three years before this study began. Consequently, organic matter content and water retention of the soils at Buena Vista site were higher than those at FB. These differences would likely explain the higher productivity of weeds and covercrop at BV. The high organic matter and associated nitrogen levels would also explain the poor performance of the legume covercrops (subterranean clover and vetch) relative to the oat covercrops. It may also explain the higher mulch breakdown rate seen at BV.

In this study, the cover crops were grown in the middles between vine rows and were concentrated into the narrower vine rows when mulched with the modified flail mower. Teasdale and Mohler (1993) estimated that at least 600 g m^{-2} of would be required to reduce light (PAR) levels to light compensation points for most species. The mulch application rates at BV were well in excess of 600 g $m\text{-}^{2}$ for all but the vetch treatment while at FB only the oat/vetch combination came close to meeting this requirement. Mulching rates at both locations resulted in similar mulch coverage (89%), yet, weed cover was higher at BV than FB for the two assessment dates after mulching in 1994. Thus, the higher weed pressure at BV relative to FB required much higher mulching rates to suppress weeds. If mulch application rates were higher at BV yet the mulch cover that persisted to subsequent years was much lower (40% at BV vs. 83% at FB) then mulch breakdown rates must be higher at BV.

Leguminous mulch should decompose more rapidly than grasses because of their low C:N ratios, which is consistent with the observations in this study (Fageria et al., 2005; Teasdale and Mohler, 1993). At BV much more of the oat mulch cover persisted from the previous year than vetch mulch assuming similar initial mulch cover following mowing as occurred in 1994. At FB, there was little breakdown of any of the mulched treatments. Therefore, it appears that the factors which limit primary productivity at FB may also limit breakdown rates of mulch cover.

Teasdale et al. (1991) found that 42% cover was required in their systems to get any weed suppression while 97% cover was required for 75% weed suppression. Based on regressions in our system, we found background weed cover varied depending on location, assessment date, and year. At BV in March of 1994, for example, background weed cover was estimated to be 95.4% while at FB it was 68.4%. These estimates are extrapolations from the existing data and should, therefore, be interpreted with caution. The linear relationship fitted for the Frei Brothers data would likely follow an exponential decay relationship as it was at Buena Vista if there were more observations below 50% mulch cover. To obtain 75% weed cover suppression would require 7.0% and 25.5% mulch cover at BV and FB, respectively. These estimates are much lower than those of Teasdale et al. (1991), and probably reflect the differences between their system and the Napa valley systems studied here. In particular, the heavier mulch production at BV, and the lack of weed pressure at FB might explain these differences.

Annual legume and grass residues may exude allelochemicals as they decompose to suppress germination and growth of weed species (Liebman and Davis, 2000; White et al., 1989). The vetch did not appear to have this effect especially at BV as weed cover was frequently highest in these plots. Allelopathy associated with the subterranean clover at FB may explain the significant weed suppression that was observed at FB. This suppression was observed year round even though it was only present during the March and June assessment dates in 1992 and 1993 and was at very low cover all of 1994.

About 85% of the weed species at BV and 78% at FB were introduced non-native species, which was somewhat higher than the 50-65% reported by Baker (1986). The composition of the weed flora at the two sites was not unusual for North Coast vineyards (Hembree and Lanini, 2006; Lanini and Bendixin, 1992). The results of the present study suggest that some species were differentially affected by the management systems. Zaragoza et al. (1989) found *C. arvensis* to be adaptable to a variety of tillage and no-tillage management systems. In the present study, we also found that *C. arvensis* cover increased gradually through the years at both locations, and ultimately became one of the dominant species in all management systems especially at the last two assessment dates.

At their best, the two conventional methods suppressed weed cover to below 10% which was similar to the best performance of the mulched treatments. In general, however, weed suppression in the herbicide and cultivation treatments were among the worst by the end of the experiment in August 1994. The high cover of *C. arvensis* in the herbicide treatment contributed most to the poor performance of this treatment. It should be noted that the herbicide mixture used in this study effectively controls annuals and will therefore tend to favor perennial species such as *C. arvensis*.

Species richness was not reduced in the herbicide treatment here as was observed elsewhere (Dastgheib and Frampton, 2000; Zargoza et al.,1989). The greatest decrease in species numbers and richness over the course of the experiment occurred in the herbicide treatment at Buena Vista soon after herbicide applications each year. However, species numbers and richness came back to their original levels by the August assessments each year. Species numbers and richness in the cultivated treatment were usually among the highest of all treatments and had a significant increase by the end of the experiment in August 1994.

Facelli and Pickett (1991) predicted that mulched systems would favor perennials, grasses, or plants with seeds of sufficient size to penetrate mulch to contact soil yet with sufficient reserves to push through mulch upon germination. In the present study, the increase in the perennial, *C. arvensis*, appeared to match those predictions. Other observations that reflected predictions were: The relatively small seeded (~2mm wide) *B. nigra* was the single most successful species at BV at the beginning of the experiment but was reduced significantly in the oat treatment where mulching levels were greatest. The relatively large seeded (up to ~55 mm including the beak-like carpel body) *Erodium* spp. were successful at FB where the mulch cover was relatively high but the mulch biomass applied and thus thickness was low. The thick of mulch at FB may have been, however, sufficiently thick to prevent the reseeding of subclover that was observed in the last year. *Stellaria media* which has small seed (~0.9-1.3mm) decreased significantly throughout this study at both locations. The Asteraceae family members, *S. oleraceus, P. echloides, C. candensis, L. serriola* with a ~3-6 mm pappus on their ~1.5-6 mm seed were successful at both locations in mulched and conventional treatments. The success of these Asteraceae species has been observed in other California vineyards and may reflect their ability to disperse from wherever they might be successful within or outside the vineyard.

This research demonstrated the ability of a mulched cover crop system to suppress weeds in vine rows that is comparable to conventional tillage and herbicidal methods. However, the cover crop must be grown in an area larger than the area intended to receive the mulched cover crop. Based on differences in cover crop and weed productivity at the two locations and the three years studied, the system appeared to be self regulating by producing an appropriate cover crop biomass for the likely weed pressure. The mechanism of significant weed suppression associated with the subclover subplots be it allelochemical or otherwise deserves further attention. There was some evidence of species compositional changes primary involving the increase in a perennial and reduction in annuals which could simply reflect the dynamics of the perennial vineyard agroecosystem. For this reason, various methods of weed suppression should be used in combination to prevent a weed flora that is tolerant of any single method used repeatedly.

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Table 1: The percent cover (mean±SE, %) remaining from the previous season (persisting cover) in the vine row in the spring of 1994. The mulched biomass (mean±SE, g m^{-2}) from vineyard middles applied to the vine rows (Biomass applied), and resulting percent cover (mean±SE, %) in the vine row following mulching (Resulting cover) at Buena Vista (BV) and Frei Brothers (FB) in the mulched main treatments: oat, vetch, oat/vetch (o/v), and residential vegetation (resid).

	Persisting cover		Biomass applied		Resulting cover	
	BV	FB	BV	FB	BV	FB
	%		$g\ m^{-2}$		%	
oat	72.3±9.2	83.5±5.1	1099±41	360±18	94.7±1.2	86.5±6.4
vetch	25.8±7.0	83.9±4.8	501±21	473±36	84.8±1.2	91.3±5.4
o/v	42.5±9.3	84.8±6.6	1367±56	514±49	90.1±2.0	87.6±5.4
resid	21.0±3.3	77.9±4.9	779±28	296±12	86.2±1.8	91.3±6.9

Table 2: Percent subterranean clover cover in the subterranean clover subplots for all assessment dates and years at Frei Brothers. Subterranean clover did not become established at Buena Vista. Any mean within a column sharing a common letter are not significantly different according to Tukey's HSD test at the 5% significance level.

	Assessment Date			
Year	**January**	**March**	**June**	**August**
	%			
1992	n/a	25.0 a	2.5 c	0.0
1993	6.1 a	41.2 a	42.0 a	0.0
1994	0.9 b	2.9 b	11.6 b	0.0

Table 3: Observed species at the Buena Vista site (a) and at the Frei Brothers site (b), common name, family, and origin. The numbers in the (BV#) column are used to reference the species depicted in the CCA diagram, Figure 5. The numbers in the (FB#) column are used to reference the species depicted in CCA diagrams, Figures 6 and 7.

(a) Buena Vista Species

BV#	Species	Common	Family	Origin
1	*Amsinckia intermedia*	coast fiddleneck	Boraginaceae	native
2	*Anagallis arvensis*	scarlet pimpernil	Primulaceae	Europe
3	*Atriplex sp.*	saltbush	Chenopodiaceae	native
4	*Avena fatua*	wild oat	Poaceae	Europe
5	*Brassica nigra*	black mustard	Brassicaceae	Europe
6	*Bromus hordeaceus*	soft brome	Poaceae	Europe
7	*Bromus diandrus*	ripgut brome	Poaceae	Europe
8	*Calandrinia ciliata*	redmaids	Portulacaceae	native
9	*Carduus pycnocephalus*	Italian thistle	Asteraceae	Med.
10	*Centaurea solstitialis*	yellow starthistle	Asteraceae	Europe
11	*Chenopodium album*	common lambsquarters	Chenopodiaceae	Europe
12	*Cirsium vulgare*	bullthistle	Asteraceae	Eurasia
13	*Convolvulus arvensis*	field bindweed	Convolvulaceae	Europe
14	*Conyza canadensis*	horseweed	Asteraceae	native
15	*Erodium moschatum*	whitestem filaree	Geraniaceae	Eurasia
16	*Erodium botrys*	broadleaf filaree	Geraniaceae	Med.
17	*Geranium dissectum*	cutleaf geranium	Geraniaceae	Europe
18	*Hordeum jubatum*	foxtail barley	Poaceae	native
19	*Hordeum vulgaer*	common barley	Poaceae	Europe
20	*Hypochoeris radicata*	hairy catsear	Asteraceae	Europe
21	*Lactuca serriola*	prickly lettuce	Asteraceae	Europe
22	*Lamium amplexicaule*	henbit	Lamiaceae	Europe
23	*Lolium multiflorum*	Italian ryegrass	Poaceae	Europe
24	*Malva parviflora*	little mallow	Malvaceae	Eurasia
25	*Medicago polymorpha*	California burclover	Fabaceae	Med.
26	*Montia perfoliata*	miners lettuce	Portulacaceae	native
27	*Picris echioides*	bristly oxtongue	Asteraceae	Med.
28	*Raphanus raphanistrum*	wild radish	Brassicaceae	Europe
29	*Rumex crispus*	curly dock	Polygonaceae	Eurasia
30	*Senecio vulgaris*	common groundsel	Asteraceae	Europe
31	*Setaria glauca*	yellow foxtail	Poaceae	Europe
32	*Silybum marianum*	blessed milkthistle	Asteraceae	Med.
33	*Solanum nigrum*	black nightshade	Solanaceae	Eurasia
34	*Sonchus oleraceus*	annual sowthistle	Asteraceae	Europe
35	*Stellaria media*	common chickweed	Caryophyllaceae	Eurasia
36	*Trifolium repens*	white clover	Fabaceae	native
37	*Xanthium spinosum*	spiny cocklebur	Asteraceae	Europe

38	*Xanthium strumarium*	common cocklebur	Asteraceae	N. Am.

(b) Frei Brothers Species

FB#	Species*	Common**	Family	Origin***
1	*Amaranthus retroflexus*	redroot pigweed	Amaranthaceae	S. Am.
2	*Avena fatua*	wild oat	Poaceae	Europe
3	*Baccharis pilularis*	coyotebush	Asteraceae	native
4	*Bassia hyssopifolia*	fivehook bassia	Chenopodiaceae	Eurasia
5	*Bromus rigidus*	ripgut brome	Poaceae	Europe
6	*Calandrinia ciliate*	redmaids	Portulacaceae	native
7	*Calendula arvensis*	field marigold	Asteraceae	Europe, Med.
8	*Capsella bursa-pastoris*	shepherdspurse	Brassicaseae	Europe
9	*Carduus pycnocephalus*	Italian thistle	Asteraceae	Med.
10	*Centaurea solstitialis*	yellow starthistle	Asteraceae	Europe
11	*Cerastium glomeratum*	sticky chickweed	Caryophyllaceae	Europe
12	*Cirsium vulgare*	bullthistle	Asteraceae	Eurasia
13	*Convolvulus arvensis*	field bindweed	Convolvulaceae	Europe
14	*Conyza bonariensis*	hairy fleabane	Asteraceae	S. Am.
15	*Conyza Canadensis*	horseweed	Asteraceae	native
16	*Digitaria sanguinalis*	large crabgrass	Poaceae	Europe
17	*Epilobium brachycarpum*	willowherb	Onagraceae	S. Am.
18	*Erodium moschatum*	whitestem filaree	Geraniaceae	Eurasia
19	*Erodium botrys*	broadleaf filaree	Geraniaceae	Med.
20	*Erodium cicutarium*	redstem filaree	Geraniaceae	Med.
21	*Euphorbia maculate*	spotted spurge	Euphorbiaceae	E. US
22	*Galium aparine*	catchweed bedstraw	Rubiaceae	native
23	*Gnaphalium palustre*	lowland cudweed	Asteraceae	native
24	*Gratiola ebracteata*	hedge hyssop	Scrophulariaceae	native
25	*Hordeum jubatum*	foxtail barley	Poaceae	native
26	*Hypochoeris radicata*	spotted catsear	Asteraceae	Europe
27	*Lactuca serriola*	prickly lettuce	Asteraceae	Europe
28	*Lamium amplexicaule*	henbit	Lamiaceae	Europe
29	*Lepidium perfoliatum*	clasping epperweed	Brassicaceae	Europe
30	*Linaria vulgaris*	yellow toadflax	Scrophulariaceae	Eurasia
31	*Lithocarpus densiflora*	tanbark oak	Fagaceae	Asia
32	*Lolium multiflorum*	Italian ryegrass	Poaceae	Europe
33	*Lupinus wyethii*	Wyeth lupine	Fabaceae	native
34	*Malva parviflora*	little mallow	Malvaceae	Eurasia
35	*Medicago polymorpha*	California burclover	Fabaceae	Med.
36	*Picris echioides*	bristly oxtongue	Asteraceae	Med.
37	*Poa annua*	annual bluegrass	Poaceae	Europe

38	*Polygonum lapathifolium*	pale smartweed	Polygonaceae	Eurasia
39	*Raphanus raphanistrum*	wild radish	Brassicaceae	Europe
40	*Rhus diversiloba*	Pacific poision-oak	Anacardiaceae	native
41	*Rhus trilobata*	squawbush	Anacardiaceae	native
42	*Rosa sp.*	rose	Rosaceae	Unknown
43	*Rubus ursinus*	California blackberry	Rosaceae	Native
44	*Rumex acetosella*	red sorrel	Polygonaceae	Eurasia
45	*Rumex crispus*	curly dock	Polygonaceae	Eurasia
46	*Senecio vulgaris*	common groundsel	Asteraceae	Europe
47	*Silybum marianum*	blessed milkthistle	Asteraceae	Med.
48	*Solanum nigrum*	black nightshade	Solanaceae	Eurasia
49	*Sonchus oleraceus*	sow thistle	Asteraceae	Europe
50	*Sorghum halepense*	johnsongrass	Poaceae	Med.
51	*Spergula arvensis*	corn spurry	Caryophyllaceae	Europe
52	*Stellaria media*	common chickweed	Caryophyllaceae	Eurasia

* Hickman, J.C., 1993.
**Weed Science Composite List of Weeds. 1984.
***Refers to native area. Native indicates California native unless specified otherwise. Abbreviations: Med.=Mediterranean, N. Am.=North America, S.Am.=South America

Table 4. Repeated measures of total weed cover at Buena Vista (BV) and Frei Brothers (FB) for the three way interactive effect of year by location and month and the two way interactive effect of year by month averaged over both locations (Both). The conventional treatments and the January assessment date were not included in the ANOVA. Multiple comparisons were performed with Tukey's HSD (α=0.05) utilizing the MSE that was utilized in assessing the effect in the repeated measures ANOVA. Means sharing a letter within a box were not significantly different according to this criterion.

	1992						1993						1994					
	March		June		August		March		June		August		March		June		August	
BV	37.0	def	28.5	def	41.0	cd	69.8	ab	19.5	h	21.9	fgh	24.1	gh	47.2	bc	20.6	gh
FB	34.5	d	3.6	j	16.2	h	69.6	a	35.7	cd	24.3	eg	11.0	i	31.9	de	7.7	i
Both	35.8	bc	16.1	f	28.6	cd	69.7	a	27.6	cd	23.1	d	17.6	e	39.5	b	14.2	e

Table 5. Repeated measures of total weed cover at Buena Vista (BV) and Frei Brothers (FB) for the two way interaction of the location by main treatment effects and the main effects of treatment across both locations (Both) and the two way interaction of the location by year effect and the year effect across both locations (Both). The conventional treatments, herbicide at BV and cultivation at FB (herb./cult.), and the January assessment date were not included in the ANOVA though the means from the conventional treatments are presented for general comparison. The year averages include the January assessments. Multiple comparisons were performed with Tukey's HSD (α=0.05) utilizing the MSE that was utilized in assessing the effect in the repeated measures ANOVA. Means sharing a letter within a box were not significantly different according to this criterion. See text for details.

	Main Treatment									Year							
	oat		vetch		oat/vetch		resident		herb./cult.	1992		1993		1994		Overall	
BV	28.3	bcd	50.5	a	27.9	bc	30.9	b	32.3	35.5	ab	37.1	b	30.7	b	34.4	a
FB	21.6	d	25.6	c	26.5	c	30.6	b	36.2	18.1	c	43.2	a	16.9	c	26.1	b
Both	24.9	b	38.0	a	27.2	ab	30.7	ab		26.8	b	40.1	a	23.8	b		

Table 6: Repeated measures analysis of variance of main treatments (trt) at Buena Vista for total percent weed cover and percent cover of the top three most dominant species before mulching (March) and at the end of the season (August) each year. The treatment means across all years were also compared. Means sharing a letter within a box were not significantly different according to a Tukey's HSD (α=0.05) multiple comparisons test. Year average comparisons include the herbicide treatments.

	March				August			
	Total Weed Cover							
trt	1992	1993	1994	mean	1992	1993	1994	mean
oat	18.5	78.5	5.9 b	34.3 b	41.1	18.0	19.4 ab	26.2
vetch	83.2	113.9	33.4 a	76.8 a	41.7	31.3	24.1 ab	32.4
o/v	33.3	62.5	17.3 a	37.7 b	30.6	16.4	22.2 ab	23.1
resident	13.1	24.4	39.9 c	25.8 c	50.4	21.9	16.9 b	29.7
herbicide	84.9	54.3	0.0 c	46.4 b	37.1	15.2	32.7 a	28.3
Mean	46.6 b	66.7 a	19.3 c		40.2 a	20.6 b	23.1 b	
	Malva parviflora				*Malva parviflora*			
oat	3.4	3.0	0.1	2.2	24.5	4.6	0.1	9.7 b
vetch	5.7	8.0	1.3	5.0	24.9	7.1	2.7	11.6 a
o/v	3.8	2.8	1.3	2.6	19.8	3.4	0.9	8.0 b
resident	2.7	3.3	0.9	2.3	28.8	5.1	2.1	12.0 a
herbicide	6.7	4.7	0.0	3.8	3.8	3.2	2.4	3.1 c
Mean	4.5 a	4.4 a	0.7 b		20.4 a	4.7 b	1.6 b	
	Brassica nigra				*Picrus echioides*			
oat	8.2 ab	30.8 ab	1.7 c	13.6 b	5.2	1.4	0.6	2.4
vetch	5.9 abc	41.2 a	19.3 a	22.1 a	7.3	12.2	3.0	7.5
o/v	4.6 bc	18.8 b	5.0 b	9.5 b	2.2	1.1	0.3	1.2
resident	3.7 c	6.6 c	13.5 a	7.9 b	7.1	3.4	0.4	3.6
herbicide	9.6 a	20.1 b	0.0 d	9.9 b	5.0	2.9	0.6	2.8
Mean	6.4 b	23.5 a	7.9 b		5.4 a	4.2 a	1.0 b	
	Sonchus oleraceus				*Convolvulus arvensis*			
oat	4.3	3.1	0.1	2.5	6.6	11.9	18.6 b	12.4 ab
vetch	5.3	4.7	0.2	3.4	3.3	8.2	14.8 b	8.8 b
o/v	4.4	3.5	1.3	3.1	5.9	11.1	19.8 b	12.3 ab
resident	1.2	1.3	0.8	1.1	8.3	9.9	13.5 b	10.6 b
herbicide	3.5	3.7	0	2.4	15.4	9.3	27.1 a	17.3 a
Mean	3.7 a	3.3 a	0.5 b		7.9 b	10.1 b	18.8 a	

Table 7: Repeated measures analysis of variance of main treatments (trt) at the Frei Brothers site for total percent weed cover and cover of the top four most dominant species before mulching (March) and at the end of the season (August) each year. The means across all years (Mean) were also compared. Means sharing a letter within a box were not significantly different according to a Tukey's HSD (α=0.05) multiple comparisons test. Year average comparisons include the cultivation treatments.

	March								August						
	Total Weed Cover														
trt	1992		1993		1994		Mean		1992		1993		1994		Mean
oat	40.8		41.5	b	9.1	bc	30.5	b	13.5		20.2		9.7		14.5
vetch	22.0		84.3	ab	10.8	bc	39.0	b	13.1		25.8		5.0		14.6
o/v	34.9		78.8	ab	4.5	c	39.4	b	12.7		27.4		8.1		16.1
resident	40.2		74.0	ab	19.8	b	44.7	b	25.3		23.8		7.9		19.0
cultivated	43.3		123.9	a	47.6	a	71.6	a	37.9		22.4		10.5		23.6
Mean	36.2	b	80.5	a	18.4	b			20.5	a	23.9	a	8.2	b	
	Stellaria media								*Sonchus oleraceus*						
oat	6.0	a	4.1	bc	0.0	a	3.4		5.5		4.4		1.3		3.7
vetch	6.8	a	18.0	a	0.0	a	8.3		5.3		10.1		0.2		5.2
o/v	4.5	a	15.9	ab	0.0	a	6.8		5.9		8.8		1.4		5.4
resident	8.1	a	5.8	abc	0.0	a	4.6		7.2		7.1		1.0		5.1
cultivated	6.6	a	3.0	c	0.0	a	3.2		10.7		8.2		4.8		7.9
Mean	6.4	a	11.0	a	0.0	b			6.0	a	7.6	a	1.0	b	
	Erodium moschatum								*Convolvulus. arevensis*						
oat	9.2	a	4.0	a	1.5	c	4.9	b	1.3		0.6		0.5		0.8
vetch	4.0	a	8.3	a	4.2	bc	5.5	b	0.1		0.1		0.6		0.3
o/v	11.9	a	12.3	a	1.0	c	8.4	b	0.5		0.8		0.6		0.6
resident	11.7	a	6.0	a	10.0	ab	9.2	ab	0.7		0.4		2.5		1.2
cultivated	16.4	a	6.9	a	26.0	a	16.4	a	0.9		0.8		1.4		1.0
Mean	9.2	a	7.7	ab	4.2	b			0.7		0.5		1.1		
	Erodium botrys								*Conyza Canadensis*						
oat	14.8	a	4.1	b	0.9	ab	6.6		0.6		0.4		2.0		1.0
vetch	3.5	b	9.6	ab	2.4	a	5.2		0.2		0.7		0.6		0.5
o/v	4.6	b	4.0	b	0.6	ab	3.1		0.1		0.3		0.7		0.4
resident	10.1	ab	28.0	a	0.0	b	12.7		0.3		0.9		1.5		0.9
cultivated	9.1	ab	31.9	a	0.0	b	13.7		0.5		0.3		0.6		0.5
Mean	8.3	a	11.4	a	1.0	b			0.3	b	0.6	ab	1.2	a	
	Poa annua								*Epilobium brachycarpum*						
oat	2.6	a	10.7	c	1.0	b	4.8	c	4.6		11.5		0.8		5.6
vetch	1.6	a	28.1	b	0.6	b	10.1	bc	9.3		11.6		0.0		7.0
o/v	9.5	a	23.8	bc	0.2	b	11.2	b	3.3		5.7		0.8		3.3
resident	2.0	a	19.3	bc	0.6	b	7.3	bc	0.5		11.7		0.5		4.2
cultivated	4.6	a	47.4	a	7.0	a	19.7	a	1.8		5.0		1.2		2.7
mean	3.9	b	20.5	a	0.6	b			4.4	ab	10.1	a	0.5	b	

Table 8: Repeated measures analysis of variance of subtreatments sowed with (+SC) and without (-SC) subclover for total weed cover and cover of the top five most dominant species before mulching (March) and at the end of the season (August) each year. The means across all years (Mean) were also compared. Multiple comparisons were performed with Tukey's HSD (α=0.05). Means sharing a letter within a box were not significantly different according to this criterion. See text for details.

	March				August			
	Total Weed Cover							
	1992	1993	1994	Mean	1992	1993	1994	Mean
+SC	31.7 a	31.4 b	2.7 b	21.9 b	3.3	4.1	2.1	3.2 b
-SC	38.0 a	77.0 a	8.6 a	41.2 a	13.4	24.5	7.4	15.1 a
mean	34.8 b	54.2 a	5.6 c		6.9 a	10.4 a	4.1 b	
	Erodium moschcatum				*Epilobium brachycarpum*			
+SC	8.2	6.3	0.6	5.0	0.0 b	0.0 b	0.0 a	0.0 b
-SC	9.7	8.6	2.5	6.9	1.1 a	3.4 a	0.2 a	1.6 a
mean	8.9 a	7.4 a	1.5 b		0.3 ab	0.5 a	0.1 b	
	Erodium botrys				*Conyza canadensis*			
+SC	6.0 a	2.1 b	0.1 b	2.7 b	1.0 a	0.9 b	0.9 b	0.9 b
-SC	6.1 a	4.4 a	0.9 a	3.8 a	1.2 a	1.4 a	1.9 a	1.5 a
mean	6.1 a	3.0 a	0.3 b		1.1	1.1	1.3	
	Stellaria media				*Sonchus. oleraceus*			
+SC	5.8	7.7	0.0	4.5	1.1	0.6	0.4	0.7 b
-SC	7.4	13.1	0.0	6.8	5.5	7.3	0.7	4.5 a
mean	6.6 a	10.2 a	0.0 b		2.5 a	2.2 a	0.5 b	
	Poa annua				*Lactuca serriola*			
+SC	0.8 a	0.8 b	0.0 b	0.5 b	0.1	0.4	0.1	0.2
-SC	1.8 a	14.0 a	0.2 a	5.3 a	0.2	1.6	0.2	0.7
mean	1.3 a	7.4 a	0.1 b		0.1 b	0.8 a	0.1 b	
	Sonchus oleraceus				*Convolvulus arvensis*			
+SC	0.0	2.9	0.2	1.0 b	0.4	0.2	0.5	0.4
-SC	0.4	8.7	1.0	3.4 a	0.4	0.4	0.6	0.5
mean	0.2 b	5.8 a	0.6 b		0.4	0.3	0.6	

Figure 1: Percent weed cover (a, b) and percent of PAR at mulch surface taken at soil level (c,d) as a function of percent weed cover at Buena Vista (a,c) and Frei Brothers (b,d) in March of 1994. Weed cover did not include the cover of *Convolvulus arvensis*. The weed cover regression at Frei Brothers does not include the subclover plots (hollow symbols). The weed cover and mulch cover (MC) relationship at BV was characterized as an exponential decay function: weed cover=95.4exp(-0.04*MC). The other relationships were described by a linear function of the general form: y=a+b*MC where at FB a=68.4, b=-0.67 for weed cover, and a=103, b=-1.03 for percent PAR and at BV a=102, b=-0.98 for percent PAR.

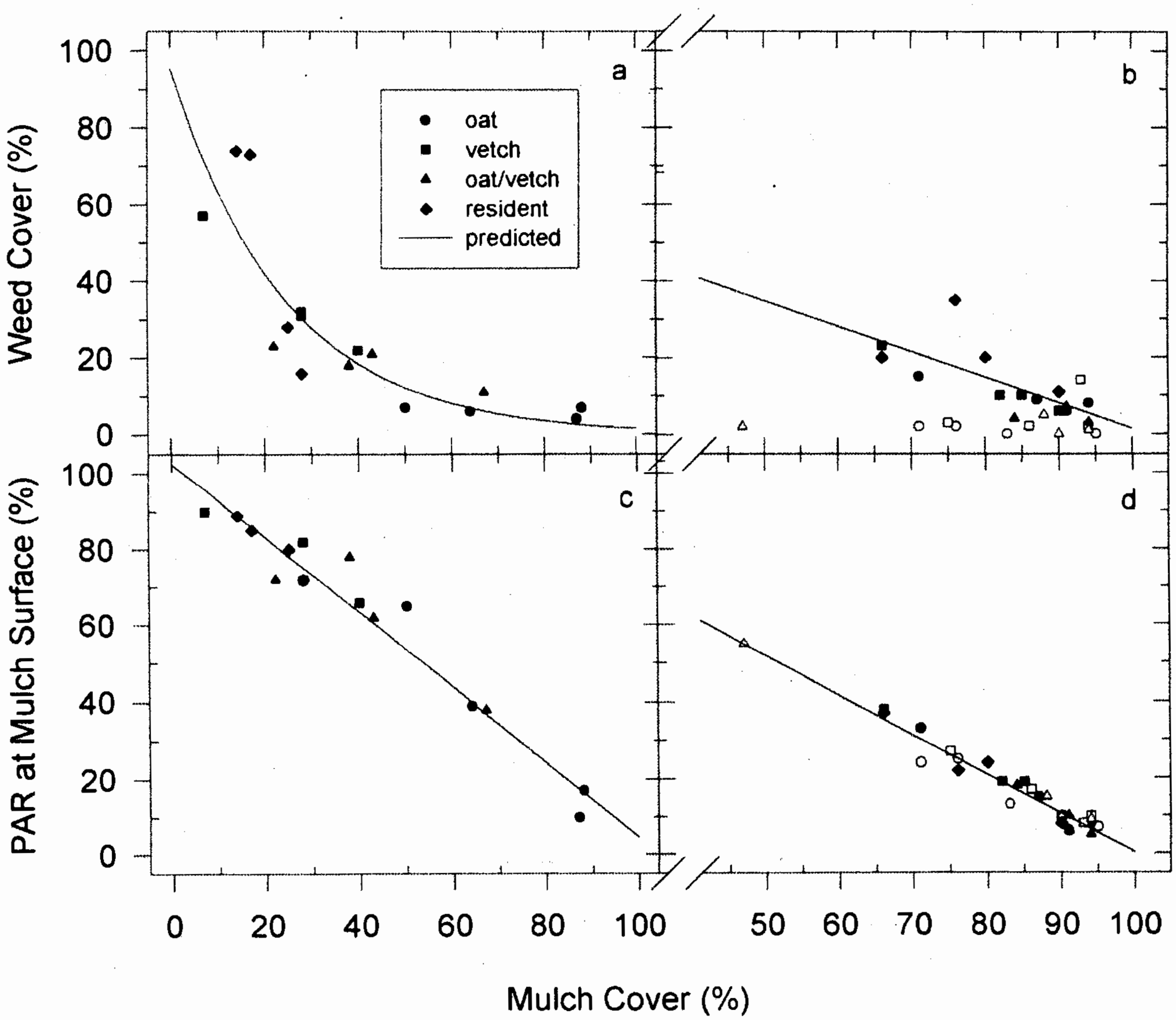


Figure 2: Observed number of weed species in the vine rows at the Buena Vista (a) and Frei Brothers (b) experimental sites from March 1992 through August 1994. A least significant difference of 2.2 was estimated by Tukey's HSD (α=0.05) utilizing the MSE that was assessed in the repeated measures ANOVA

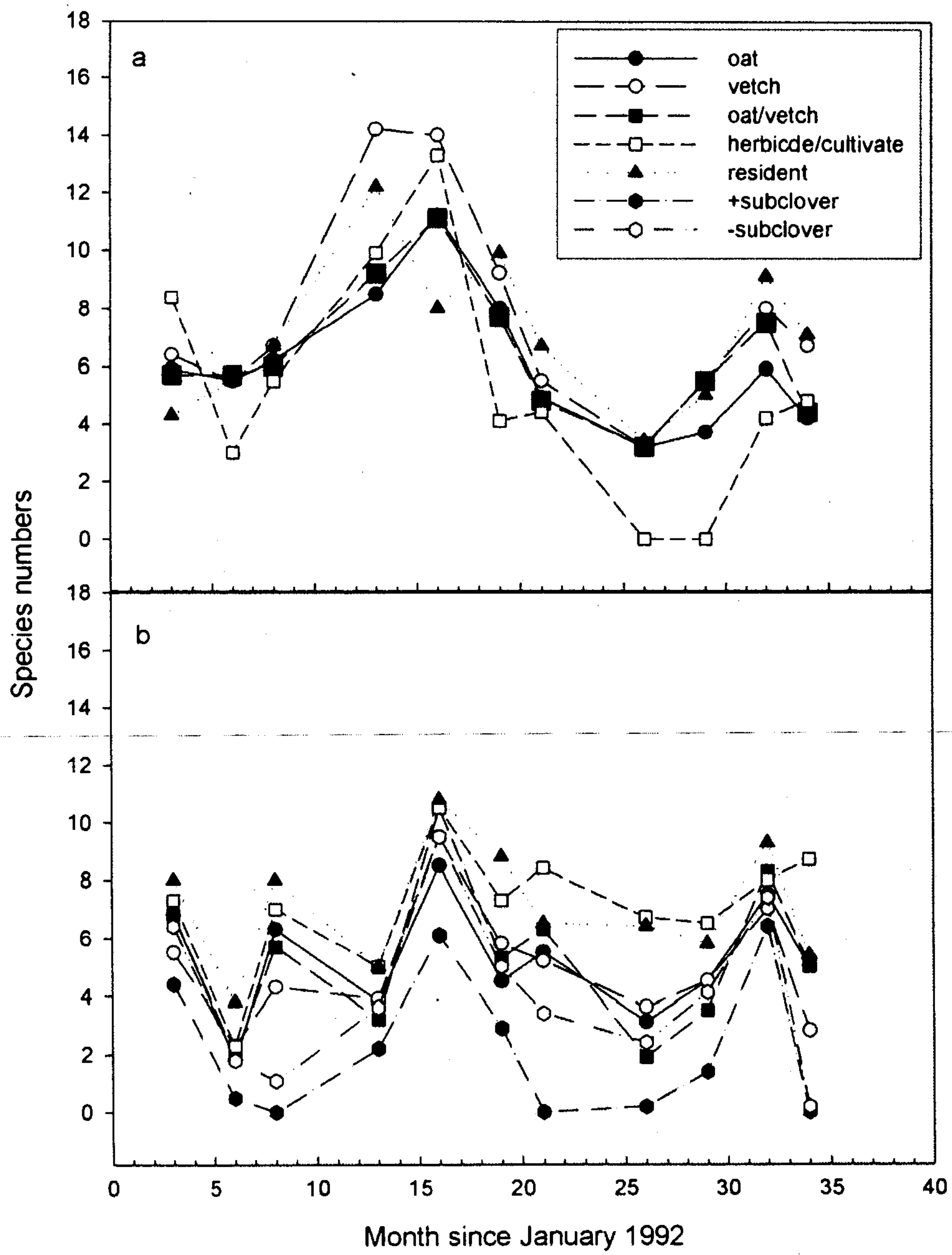


Figure 3: Change in jackknife weed species richness estimators from March 1992 to March 1994 (black bar) and from August 1992 to August 1994 (gray bar) at Buena Vista (a.) and Frei Brothers (b.) in each of the main treatments. The bars with asterisks represent the herbicide treatment in (a.). Standard error bars were based on the square root of the jackknife estimates of the variance divided by the sample size.

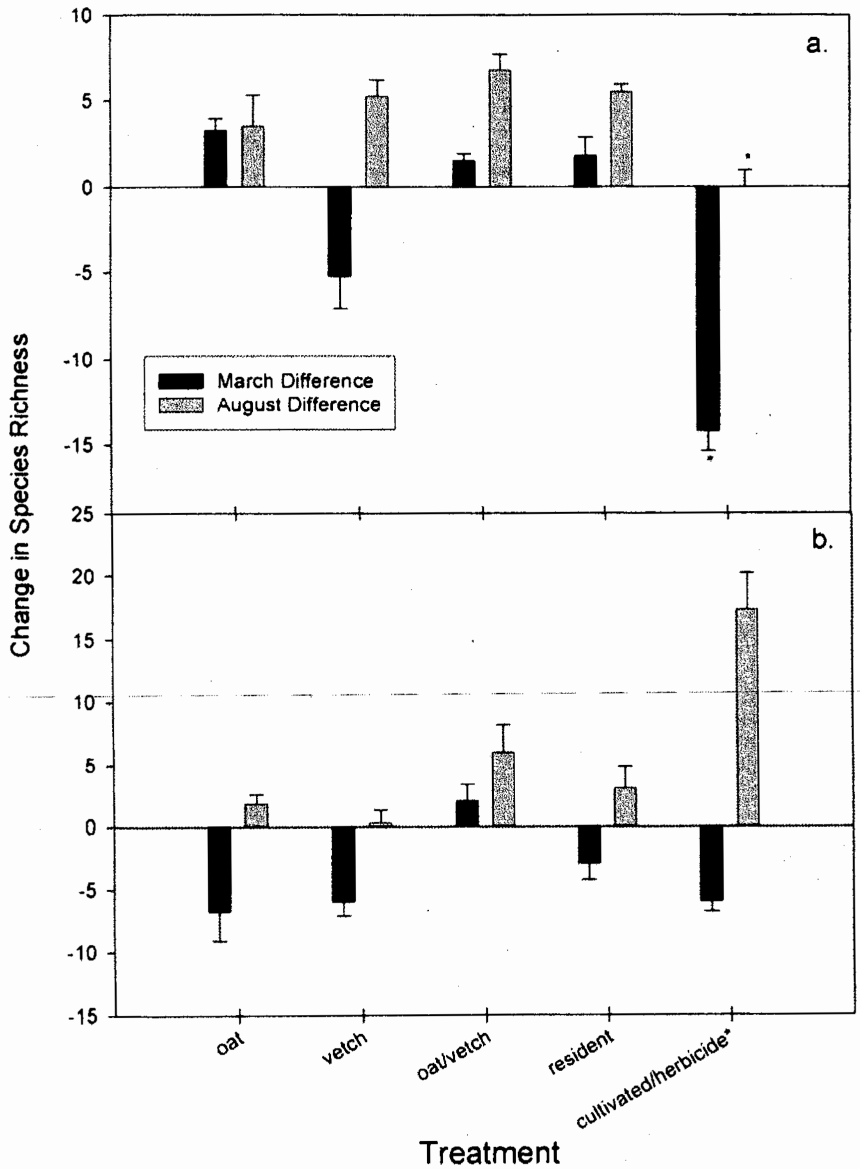


Figure 4: Change in jackknife weed species richness estimators from March 1992 to March 1994 (black bar) and from August 1992 to August 1994 (gray bar) in the subplots with subclover (+SC) and without subclover (-SC) at Frei Brothers. Standard error bars were based on the square root of the jackknife estimates of the variance divided by the sample size.

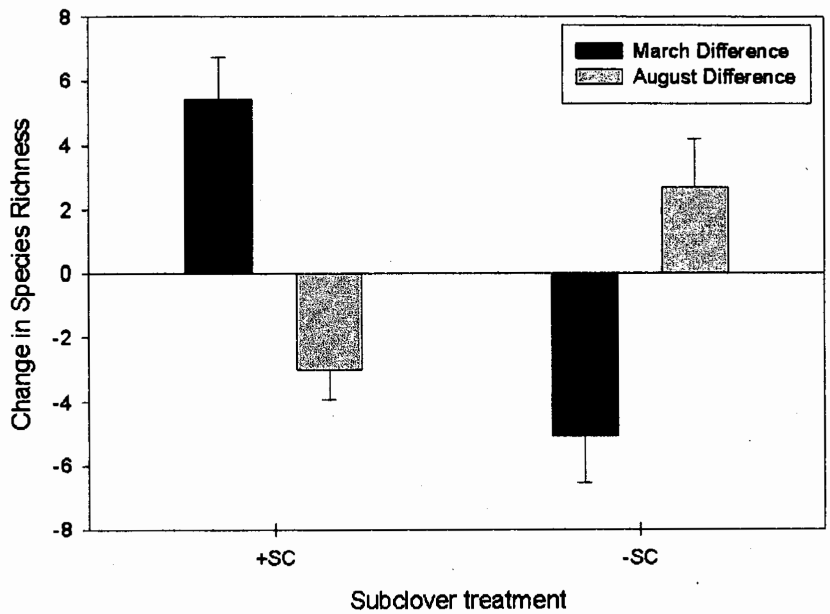


Figure 5. Canonical Correspondence Analysis biplots of species scores (numbers) and environmental variables (arrows and squares) at Buena Vista for the March and August assessment dates. Species numbers are those as listed in Table 3. Environmental variables correspond with mulch cover, time (year), precipitation (rain) for the three month prior to the assessment date, and cumulative rain (cumrain) beginning in November of each year (red arrows). Environmental variables corresponding to the main treatments (oat, vetch, oat/vetch, resident, herbicide) were coded as nominal variables and their centroids are plotted (■).

Figure 6. Canonical Correspondence Analysis biplots of species scores (numbers) and environmental variables (arrows and squares) at Frei Brothers for the March and August assessment dates. Species numbers are those as listed in Table 3. Environmental variables correspond with mulch cover, time (year), precipitation (rain) for the three month prior to the assessment date, and cumulative rain (cumrain) beginning in November of each year (red arrows). Environmental variables corresponding to the main treatments (oat, vetch, oat/vetch, resident, cultivated) were coded as nominal variables and their centroids were plotted (■).

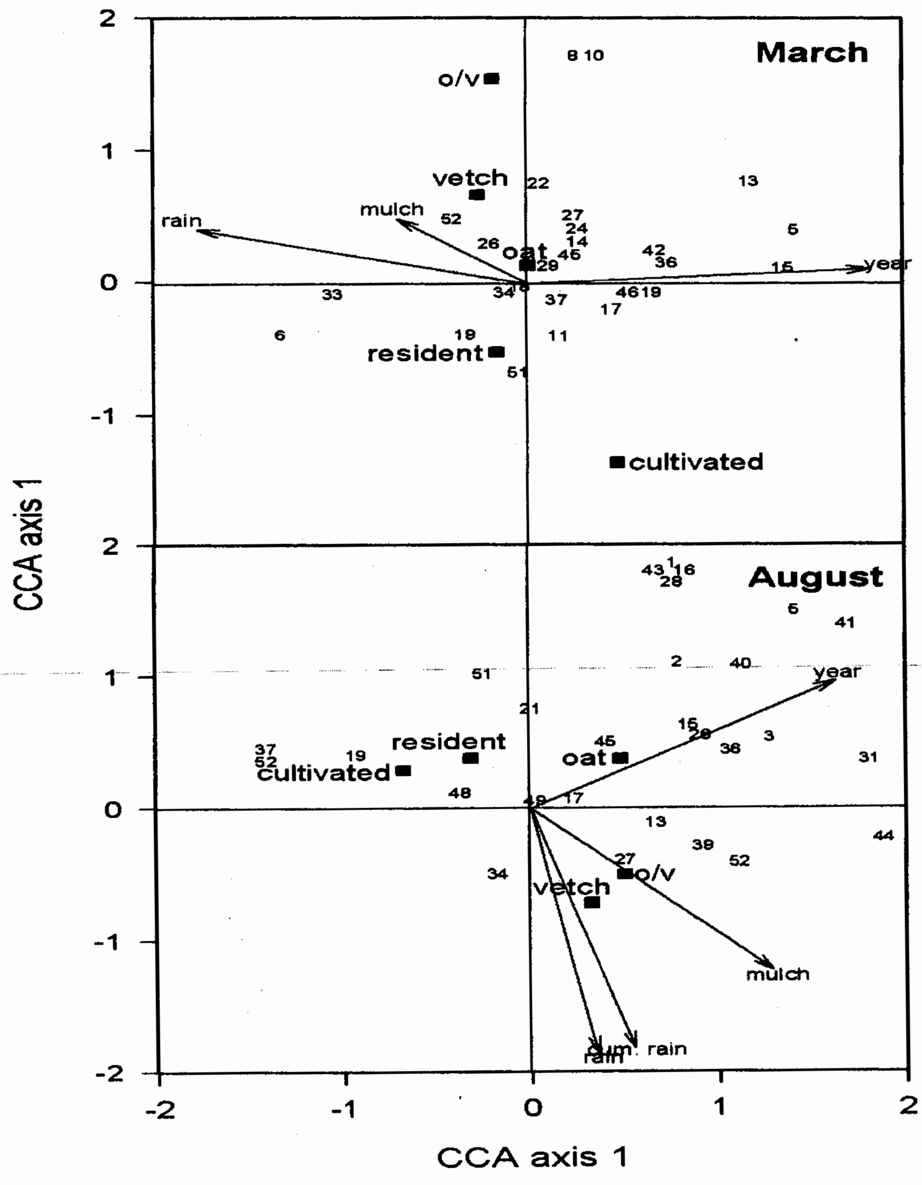


Figure 7. Canonical Correspondence Analysis biplots of species scores (numbers) and environmental variables (arrows and squares) at Frei Brothers for the March and August assessment dates. Species numbers are those as listed in Table 3. Environmental variables correspond with mulch cover, time (year), precipitation (rain) for the three month prior to the assessment date, and cumulative rain (cumrain) beginning in November of each year (red arrows). Environmental variables corresponding to the main treatments (oat, vetch, oat/vetch) and subtreatments (subtrt) were coded as nominal variables (■).

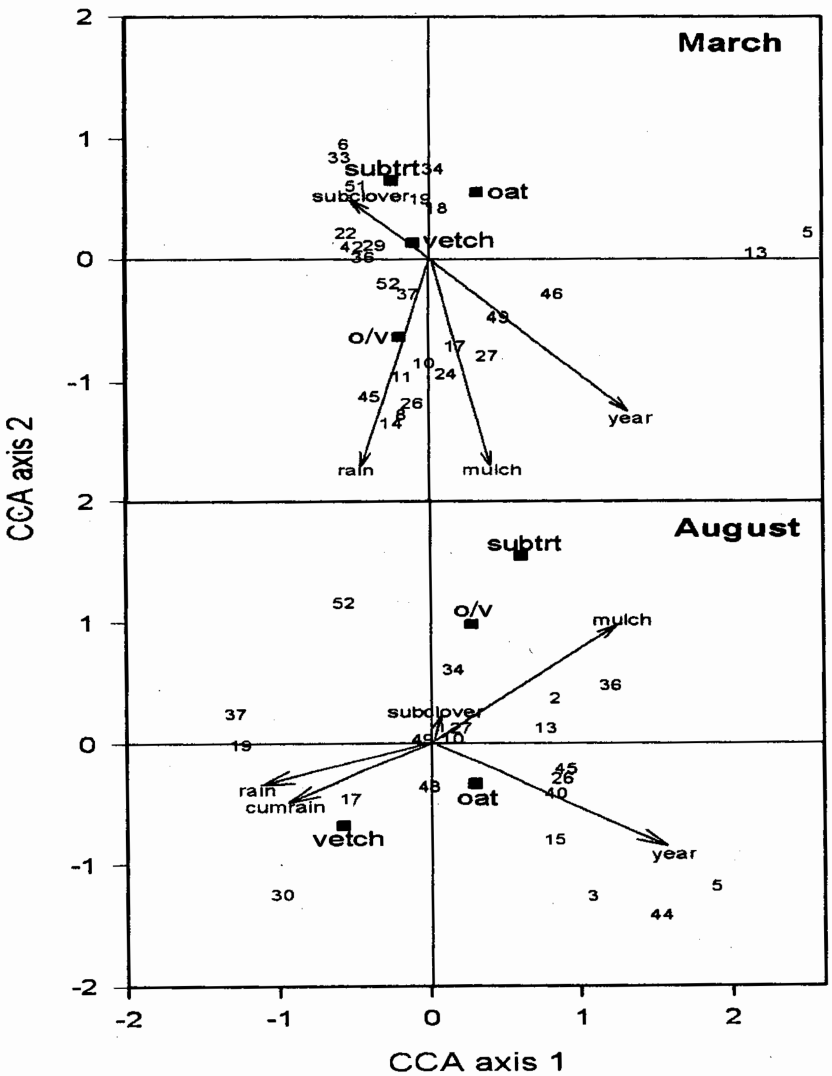
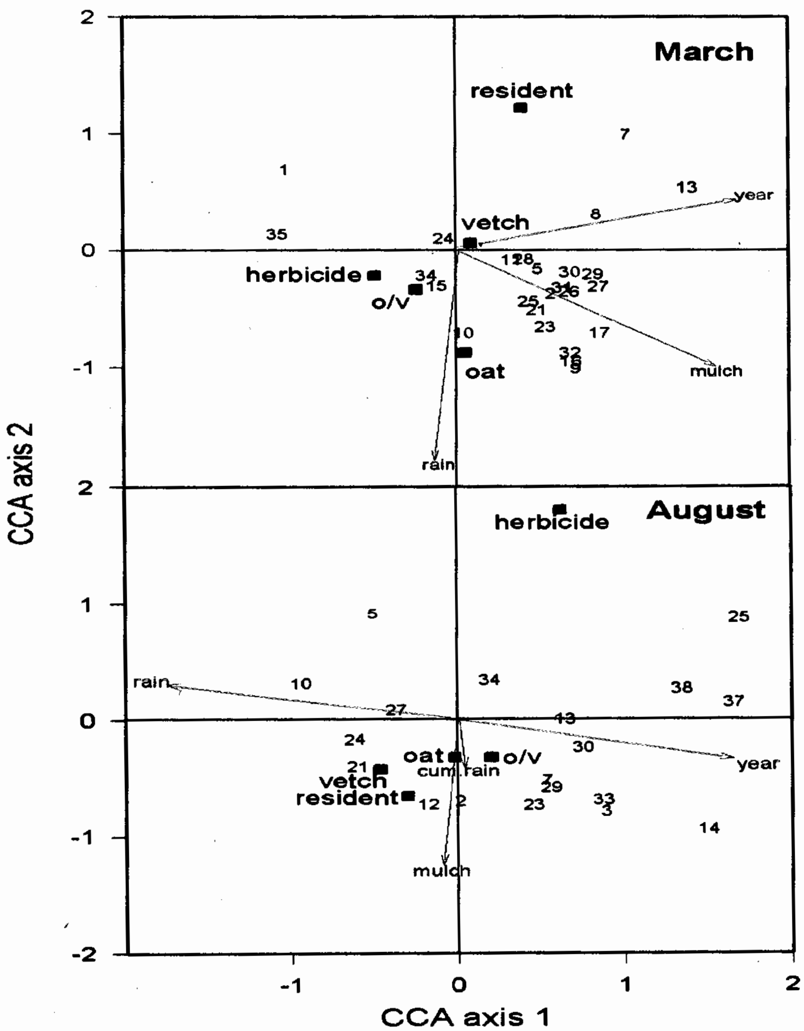


Figure 5. Canonical Correspondence Analysis biplots of species scores (numbers) and environmental variables (arrows and squares) at Buena Vista for the March and August assessment dates. Species numbers are those as listed in Table 3. Environmental variables correspond with mulch cover, time (year), precipitation (rain) for the three month prior to the assessment date, and cumulative rain (cumrain) beginning in November of each year (red arrows). Environmental variables corresponding to the main treatments (oat, vetch, oat/vetch, resident, herbicide) were coded as nominal variables and their centroids are plotted (■).



Plantains

UC PEER REVIEWED

Integrated Pest Management for Home Gardeners and Landscape Professionals

Broadleaf and buckhorn plantain (*Plantago major* and *P. lanceolata*) are two major perennial weeds in California. These weeds can be found in turfgrass, ornamental plantings, gardens, roadsides, and pastures. Both species are found throughout the state and grow year-round, except in the coldest intermountain areas and deserts.

The genus *Plantago* consists of about 250 species worldwide, with 20 species found in California. Both broadleaf and buckhorn plantain were introduced from Europe. Broadleaf plantain (Figure 1) is also known as common plantain and dooryard plantain. Other names for buckhorn plantain (Figure 2) include narrow-leaf plantain, ribwort plantain, English plantain, and ribgrass.

Figure 1. Broadleaf plantain, *Plantago major*.

IDENTIFICATION AND LIFE CYCLE

Broadleaf plantain (Figure 1) commonly occurs in moist areas with full sun or partial shade and compacted soil. It has a tough short crown with fibrous roots attached. The smooth, oval leaf blades are 2 to 7 inches long with several veins that parallel the leaf margins. The leaf veins meet at the base to form a broad petiole (leaf stem). The flowering stalks can reach 15 inches tall, and stalks are topped with a dense spike of small flowers (Figure 3). Seeds are black or brown and 1/16 inch in diameter.

Unlike broadleaf plantain, buckhorn plantain (Figure 2) grows best in disturbed sites. It has a taproot and longer, narrower leaves 3 to 12 inches long with parallel veins. The blade merges smoothly into the petiole, which is shorter than that of broadleaf plantain. The plant crown—the growing point at the soil surface—is covered with tan, woolly hairs. The flowering stalks of buckthorn plantain can reach 18 inches tall. As it blooms, stamens protrude from the flower head (Figure 4). Seeds are black, shiny, and about 1/16 inch in diameter.

Figure 2. Buckhorn plantain, *Plantago lanceolata*.

Plantain seeds germinate at or near the soil surface when soil moisture is adequate and soil temperature reaches 50°F. Ideal germination temperature is around 77°F; however, germination happens more rapidly as temperatures increase. The seedling stage for broadleaf plantain (Figure 5) and buckhorn plantain (Figure 6) can last

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