Seeding Rate and Planting Arrangement Effects on Growth and Weed Suppression of a Legume-Oat Cover Crop for Organic Vegetable Systems

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ABSTRACT

Winter cover crops can add soil organic matter, improve nutrient cycling, and suppress weeds in organic vegetable systems. A 2-yr study was conducted on organic farms in Salinas and Hollister, CA, to evaluate the effect of seeding rate (SR) and planting arrangement on cover crop density, ground cover, and cover crop and weed dry matter (DM) with a mixed cover crop. The mix contained legumes (35% *Vicia faba* L., bell bean; 15% *Vicia dasycarpa* Ten., woolypod vetch; 15% *Vicia benghalensis* L., purple vetch; and 25% *Pisum sativum* L., pea) and 10% oat (*Avena sativa* L.) by seed weight. Three SRs (112, 224, and 336 kg ha^{-1}) and two planting arrangements (one-way versus grid pattern) were evaluated. Planting arrangement had no effect on the variables measured. When weeds were abundant, weed DM declined linearly with increasing SR from approximately 300 kg ha^{-1} at the low SR to <100 kg ha^{-1} at the high SR. Increasing SR increased oat and legume DM early in the season, but did not affect final cover crop DM that ranged from 7 to 12 Mg ha^{-1}. Year affected final cover crop DM production at both sites. The legume DM portion of the total cover crop declined through the season but varied between sites and year, probably due to soil and climatic differences. Higher SRs may be cost effective because weed control is expensive and cover crop seed is a relatively small component of cover cropping costs in this region.

Organic vegetable production is an important agricultural sector on the central coast of California. For example, in 2007, 111 farms in Monterey County produced $226 million of organic crops (County of Monterey, 2007, p. 22). Annual rotations in these systems typically include two or more vegetable crops during the warmer periods, followed by a fallow period, cover, or vegetable crop in the cool season. The benefits of cover crops on soil and water quality are well documented (Cherr et al., 2006; Dabney et al., 2001; Fageria et al., 2005). Cover crops are particularly useful for improving N-use efficiency in high-input cropping systems (Tonitto et al., 2006) and have been the focus of several studies with cereal rye (*Secale cereale* L.) on conventional farms in the central coast of California (Jackson, 2000; Wyland et al., 1996). In this region, winter cover crops are more common on organic than conventional farms and often include mixes of legumes and cereals. Ranells and Wagger (1997) reported that, in some years, the N content of a rye-vetch was more than twice as high as in rye monoculture, presumably because such a mix combined the N scavenging characteristics of the cereal with the N fixing ability of the legume.

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Weed growth in winter cover crops on the central coast is problematic because many weed species germinate all year, and weed seed produced during the winter may increase weed management costs in subsequent cash crops. Brennan and Smith (2005) reported that weed growth and seed production can be especially high in legume-oat cover crop mixes and suggested that this could be reduced by increasing the SR. Seeding rates have been extensively studied in cash crops and can affect crop yield, light interception, weed growth, and weed seed production (Blackshaw et al., 1999; Mohler, 2000; Shield et al., 2002; Teasdale, 1995, 1998). Neighboring plants compete for light, nutrients, and water earlier in the season as plant density increases (Harper, 1977). Few studies have investigated SRs with cover crop mixes (Akemo et al., 2000; Clark et al., 1994).

Planting arrangement is known to affect crop competitive ability (Mohler, 2000). For example, increasing planting uniformity can increase yield and reduce weed growth in some crops (Olsen et al., 2005a, 2005b; Weiner et al., 2001). A simple way to increase planting uniformity is to plant rows in a grid pattern with each pass at half the SR used to plant the normal one-way direction. The effect of planting arrangement on growth and weed suppression in cover crop mixes has not been studied.

The objective of our study was to investigate the effects of SR and planting arrangement on cover crop density and ground cover, cover crop DM production, and weed suppression with a mixed cover crop of legumes and oat. We hypothesized (i) that weed suppression would increase with cover crop SR, (ii) that early-season ground cover would be greater in a grid than in a one-way planting arrangement, and (iii) that a grid planting arrangement would be more weed-suppressive than a one-way planting arrangement.

Abbreviations: DAP, days after planting; DM, dry matter; SR, seeding rate.

MATERIALS AND METHODS

The study occurred during two consecutive winters (November to April) from 2003 to 2005 on certified organic farms in Hollister and Salinas, CA. The Hollister site is a diversified organic vegetable and fruit farm and the soil is a Clear Lake Clay (fine, smectitic, thermic Xeric Endoaquerts). The Salinas site is the USDA-ARS organic research farm and the soil is a Chualar loamy sand (fine-loamy, mixed, thermic Typic Argixerol). Different fields were used at each site during each winter. The Hollister site has been in an intensive organic vegetable and cover crop rotation since 1990 with annual additions of compost and supplemental organic fertilizers. Bulb onions (*Allium cepa* L.) and melons (Cucurbinaceae) were grown in 2003 and 2004, respectively, before the Hollister trial. In contrast, the Salinas site was used for winter oat hay production from 1990 to 1996, followed by frequent fallow periods and occasional organic vegetables and cover crops with minimal additions of compost or supplemental organic fertilizers. Buckwheat (*Fagopyrum esculentum* Moench) cover crop and baby leaf spinach (*Spinacea oleracea* L.) were grown in 2003 and 2004, respectively, before the Salinas trial.

A RCBD with four blocks was used at each site. There were six treatments, including three SRs (1× = 112, 2× = 224, 3× = 336 kg ha^{-1}) and two planting arrangements (one-way versus grid drilling) in Hollister. In Salinas, the three SRs were evaluated only in the one-way planting arrangement. In Hollister, the plots were 12 by 12 m, with 12-m buffers that were used for a turning area to achieve the grid pattern and then seeded at approximately the 1× rate. The plots were 12 by 15 m in Salinas. Sprinkler irrigation was used as necessary to stimulate germination at both sites before the onset of winter rainfall, and 0.6 mm of sprinkler irrigation was also applied in the late spring (17 March) of Year 2 in Salinas.

Field preparation included disking and harrowing. The cover crop was planted with a 4.6-m-wide grain drill (Model 1500, Great Plains Mfg., Salina, KS) with 15-cm row spacing. The drill had double disc openers that preceded rubber press wheels, and was modified with four seed cones (Kinkaid Equipment Mfg., Haven, KS) for precise control of SR in small plots. Planting dates were 3 and 8 November in Hollister, and 4 and 9 November in Salinas in 2003 and 2004, respectively. In this paper, Year 1 and Year 2 refer to the cover crop periods from 2003 to 2004, and from 2004 to 2005, respectively.

The cover crop mix included the following components by seed weight: 10% 'Cayuse' oat, 35% bell bean, 25% 'Magnus' pea, 15% 'Lana' woolypod vetch, and 15% purple vetch. Bell bean is a relatively small-seeded type of *V. faba* that is widely used in cover crop mixes in California. The 1000-kernel weights (g) of the components were oat (33.7, 30.4), bell bean (417.4, 436.0), pea (239.0, 231.0), wollypod vetch (40.1, 33.8), and purple vetch (38.0, 32.2) in Year 1 and Year 2, respectively. The 1000-kernel weights of the mixes were 79.7 (Year 1) and 70.0 (Year 2). The cover crop seed was inoculated with Rhizo Stick *Rhizobium* innoculant (Urbana Laboratories, St. Joseph, MO) before planting.

Cover crop ground cover was determined by holding a 30- by 30-cm quadrat with 64 cross grid intersections approximately 50 cm above the ground and counting grid intersections that were over cover crop vegetation. These values were converted to percentage ground cover. Ground cover was only determined in Hollister 29 days after planting (DAP) in Year 1, and at 24 DAP in Year 2. Cover crop population density was determined by counting cover crop plants in three 50- by 50-cm quadrants per plot at 18 or 24 DAP in Hollister, in Years 1 and 2, respectively, and at 27 DAP in both years in Salinas. Emerged weeds were counted in 50- by 50-cm quadrants at 29 and 35 DAP in Year 1 and Year 2, respectively, in Hollister. Weed emergence was not determined in Salinas.

Aboveground DM of cover crops was determined in one 100- by 50-cm, or one 50- by 50-cm quadrant in each plot at four harvest dates during each year (Fig. 1). The specific harvest dates were chosen to track changes in biomass through the cover cropping period. Aboveground weed DM was determined in the same quadrants as cover crop DM on all except the last harvest each year when most weeds had senesced. Cover crop samples were separated into legume and oat components and were oven dried with the weeds at 65°C for at least 48 h until the weight had stabilized. The last harvest at both sites occurred after most cover crops plants had flowered but before viable seed production.

The data were subjected to ANOVA with the MIXED procedure in SAS version 9.1 (SAS Institute, Cary, NC) for each site separately. Dependent variables were oat, legume, and weed DM production at both sites, and percentage ground cover in Salinas. Independent variables were year, SR, and harvest date at both sites, and also planting arrangement in Hollister. Data were transformed as needed to meet the assumptions of equal variance and normality, but back-transformed means are presented. Linear and quadratic contrasts were used to determine the significance of SR. For analysis of total cover crop density at both sites, the reciprocal square root transformation was used with block as a random effect, and SR, year, and their interactions as fixed effects. For the analysis of ground cover, cover crop density, and weed emergence in Hollister, block was a random effect, and SR, year, planting arrangement and their interactions were fixed effects. For analysis of aboveground DM, harvest was a repeated effect with the Toeplitz covariance structure at both sites with the subject = year × SR × orient × block for Hollister, and subject = year × SR × block for Salinas. For aboveground DM analyses in Hollister, block, block × SR × orient, and block × SR × orient × year were random effects, and SR, year, planting arrangement, harvest and their interactions were fixed effects. For DM analyses in Salinas, block, block × SR, and block × SR × year were random effects, and SR, year, harvest and their interactions were fixed effects. Initial analyses of DM were conducted with the full model across years. Subsequent analysis of DM were stratified by year and harvest due to differences in the harvest intervals each year, and significant year and harvest effects. The planting arrangement effect was dropped from the stratified analyses in Hollister because it was not significant for any factor in the initial analyses. Transformations used in the DM analyses in Salinas were natural log for total cover crop, legume, oat, and weed + 1. Transformations used in the DM analyses in Hollister were natural log of oat, total cover crop + 1, weed + 1, legume + 1. Linear contrasts were used to determine when DM production had stabilized within SR and year. In all analyses, significance was determined at the $P \leq 0.05$ level.

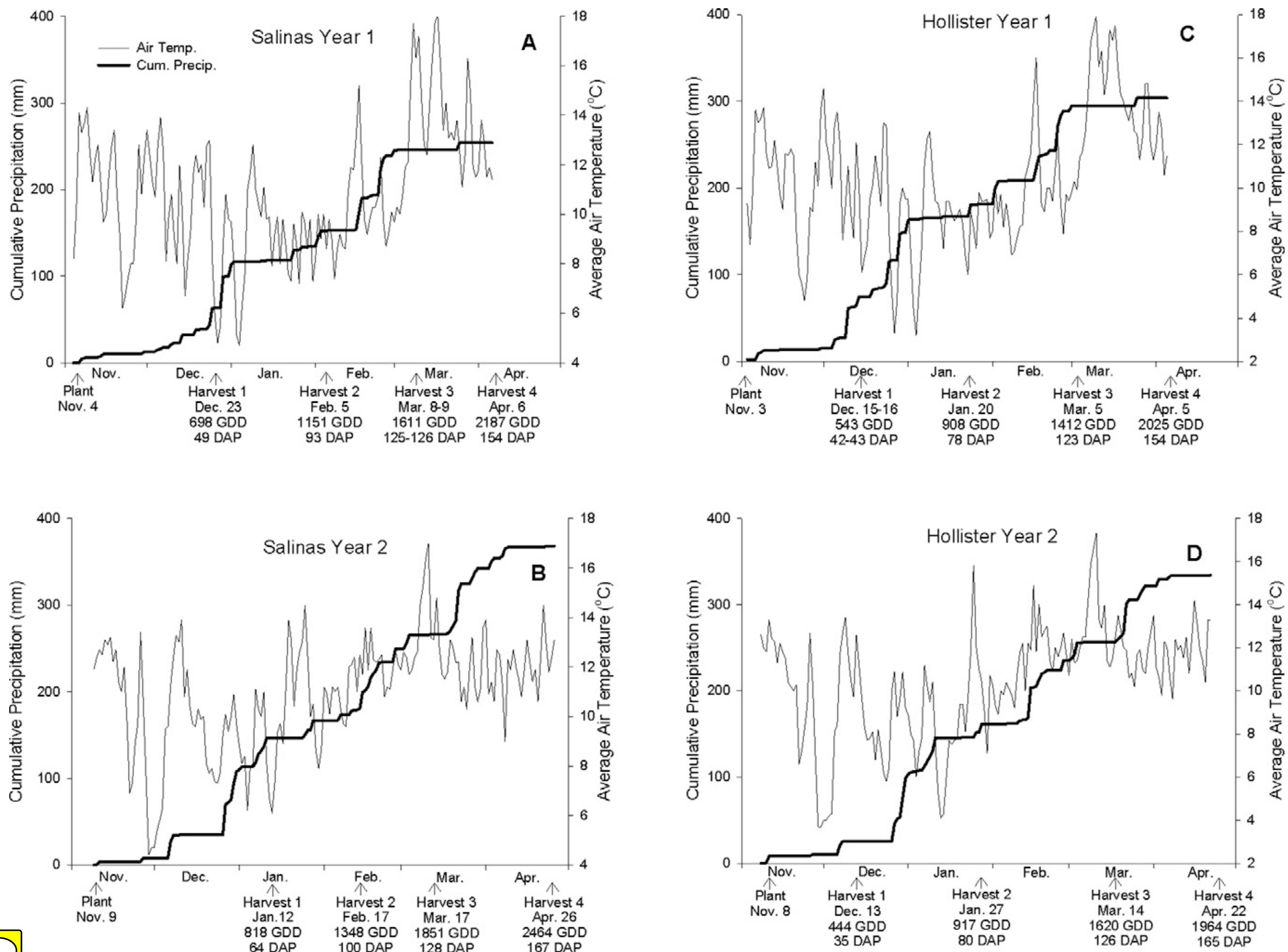

Fig. 1. Cumulative precipitation and daily average air temperature from the California Irrigation Management Information System in Year 1 (2003–2004) and Year 2 (2004–2005) at Salinas (A, B, Station 89) and Hollister (C, D, Station 126) available at http://wwwcimis.water.ca.gov [verified 13 Apr. 2009]. The 13-yr average rainfall between November and April (1993–2007) was 395 mm (Hollister) and 346 mm (Salinas). Dry matter harvest dates, growing degree day (GDD) accumulation, and days after planting (DAP) are indicated for each site and year. The GDD were calculated with the single sine method with a baseline threshold of 4°C using the online calculator at the University of California Statewide Integrated Pest Management web site, http://www.ipm.ucdavis.edu [verified 13 Apr. 2009].

RESULTS AND DISCUSSION

Climate

Rainfall was higher in Year 2 than Year 1, and was below the 13-yr average both years in Hollister, and in Year 1 in Salinas (Fig. 1). Irrigating winter cover crops during dry periods is seldom a cost effective option because the sprinkler pipes used to germinate the crop are removed early in the fall before they are covered with vegetation. Intermittent irrigation in winter cover crops is possible with linear-move irrigation systems; however, these are less common in the area than the hand-moved sprinkler systems. Late rainfall as occurred in Year 2 can be problematic if cover crops produce seed or when excessive soil moisture delays field preparation for spring vegetable plantings that typically occur 4- to 6-wk after mowing and incorporating the cover crop in February or March. The need for early spring vegetable plantings is a major barrier to cover cropping in the region, and is why most fields are fallow over the winter and why farms that use cover crops frequently keep some fields fallow over the winter.

Planting Arrangement

Planting arrangement had no affect on cover crop or weed DM production (Table 1). This results agrees with a study with a rye cover crop that reported inconsistent effects of planting arrangement on rye and weed DM (Boyd et al., 2009). In contrast, studies elsewhere reported improved weed suppression, and higher DM and grain yield in wheat planted in a grid versus the normal row pattern (Olsen et al., 2005a; 2005b; 2006; Weiner et al., 2001). We speculate that any potential benefits from increased spatial uniforming in the grid pattern were cancelled by the increased diversity in canopy and root architectures in the mixed cover crop in our study. Under our field conditions, planting in a grid pattern was more difficult than one-way planting because of the need to drive slower to avoid bouncing as the tractor crossed over the wheel tracks from the first planting direction. Furthermore, grid planting requires twice as many passes over a field as the one-way pattern and thus increases fuel use, labor costs, driver fatigue, planting time, tractor maintenance costs, soil compaction, and dust production.

Table 1. Significance of tests of fixed effects and interactions on aboveground dry matter (DM) of total cover crop, legume, oat, and weeds based on the MIXED procedure across 2 yr in Salinas and Hollister, CA.

Site	Effect	DM type: Total cover crop†	Legume	Oat	Weed
Salinas	Harvest	***	***	***	***
	Year	**	***	***	***
	Rate‡	***	***	**	***
	Harvest × rate	***	**	NS§	NS
	Year × rate	NS	NS	*	NS
	Harvest × year	***	***	***	***
	Harvest × year × rate	NS	NS	*	***
Hollister	Harvest	***	***	***	***
	Year	***	***	***	***
	Rate	***	NS	***	**
	Arrangement¶	NS	NS	NS	NS
	Harvest × rate	***	***	***	**
	Year × rate	NS	NS	NS	NS
	Harvest × year	***	**	***	***
	Harvest × year × rate	NS	NS	NS	NS

* Significant at the $P \leq 0.05$ level.

**Significant at the $P \leq 0.01$ level.

*** Significant at the $P \leq 0.001$ level.

† Total cover crop DM is legume + oat.

‡ Seeding rates were 112 kg ha^{-1}, 224 kg ha^{-1}, and 336 kg ha^{-1}

§ NS, not significant.

¶ Planting arrangements included a grid pattern versus a one-way pattern.

Cover Crop Density

Cover crop density was higher in Year 2 in Salinas, but higher in Year 1 in Hollister ($P < 0.001$) (Table 2). These differences were apparent in the density of each component in the mix. As a percentage of planted seed, total cover crop emergence across SRs was 59 and 78% in Salinas, and 100 and 65% in Hollister, in Years 1 and 2, respectively. As expected, increasing the SR increased the total cover crop density at both sites ($P < 0.001$), however, proportionally fewer seeds emerged as rate increased during both years in Salinas ($P \leq 0.01$). For example, total emergence was 69% (97 plants m^{-2}) of the expected density (140 plants m^{-2}) at the 1× rate, versus only 51% (216 plant m^{-2}) of the expected density (420 plants m^{-2}) at the 3× rate in Year 1 in Salinas. Thus in Year 1, the 2× rate had only 1.7 times more plants than the 1× rate, and the 3× rate had only 2.2 more plants than the 1× rate in Salinas. The SR did not affect the proportion of planted seeds of each component that emerged. The percentage of plants in the mix averaged across years, sites, and SRs was 26% oat, 9% pea, 60% vetch, and 6% bell bean. The ratio of legume to oat plants was unaffected by SR or year at either site.

Cover crop density and 1000-kernel weight are seldom reported in cover crop studies, but provide useful information to understand differences in cover crop performance between and within sites, and may be particularly useful with mixed cover crops. The 95% confidence intervals for cover crop densities indicate more variability in Salinas than in Hollister both years (Table 2). This greater variability in Salinas than Hollister may be due to biotic differences (predation, germination, emergence) between sites and years, and may also be due to the larger subsampling area for each SR in Hollister than in Salinas; densities in Salinas were based on one plot per SR per replicate, whereas in Hollister densities were based on two plots (one-way and grid pattern) per SR per replicate. The distribution of larger seeded components (i.e., pea and bell bean) in the mixed cover crops planted in a single pass tended to be less uniform than that of smaller-seeded, more numerous components, and thus may have required a larger sampling area to accurately determine population densities. It is also interesting to note the density differences at the same SR across sites. For, example, in Year 1, although we used the same cover crop mix and planting equipment at both sites, the density (216 plants m^{-2}) at the 3× rate in Salinas is less than the density (298 plants m^{-2}) at the 2× rate in Hollister. Weiner et al. (2001) reported higher wheat emergence in a grid planting pattern than one-way pattern during some years; however, planting arrangement did not affect cover crop emergence in our study.

Cover Crop Ground Cover

The SR and year had significant effects on percentage ground cover ($P < 0.001$) in Hollister, but was not measured in Salinas. Contrary to our hypothesis, percentage ground cover by the cover crops was not greater in the grid than one-way planting arrangement. Ground cover by cover crops increased linearly

Table 2. Mean population densities (± 95% confidence intervals) of cover crop components and total cover crop in Salinas and Hollister, CA, at three seeding rates (1×, 2×, 3×) in Year 1 (2003–2004) and Year 2 (2004–2005).

Site	Mix component	Year 1: 1×†	Year 1: 2×	Year 1: 3×	Year 2: 1×	Year 2: 2×	Year 2: 3×
		plants m^{-2}‡					
Salinas	bell bean	8 ± 7	11 ± 5	17 ± 3	9 ± 6	10 ± 7	20 ± 15
	pea	7 ± 1	11 ± 5	20 ± 13	9 ± 11	16 ± 7	33 ± 13
	vetches	54 ± 16	101 ± 22	128 ± 31	82 ± 22	13 ± 45	214 ± 52
	oat	29 ± 8	38 ± 13	52 ± 12	44 ± 23	55 ± 17	104 ± 22
	total	97 ± 20	161 ± 36	216 ± 43	143 ± 31	212 ± 52	370 ± 46
Hollister	bell bean	8 ± 2	21 ± 2	25 ± 6	7 ± 3	13 ± 3	19 ± 5
	pea	17 ± 3	34 ± 5	45 ± 4	10 ± 4	14 ± 4	29 ± 7
	vetches	81 ± 4	175 ± 10	237 ± 27	61 ± 8	123 ± 20	204 ± 23
	oat	35 ± 3	68 ± 12	94 ± 11	25 ± 6	45 ± 6	76 ± 10
	total	140 ± 5	298 ± 19	400 ± 32	103 ± 13	196 ± 23	326 ± 33

† Seeding rates were 1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, and 3× = 336 kg ha^{-1}.

‡ Densities are averaged across one-way and grid planting arrangement in Hollister. Expected densities at the 1× rates, assuming all seeds emerged for Year 1 and 2, respectively, were bell bean (9, 9), pea (12, 12), vetch (86, 102), oat (33, 37), and total (140, 160).

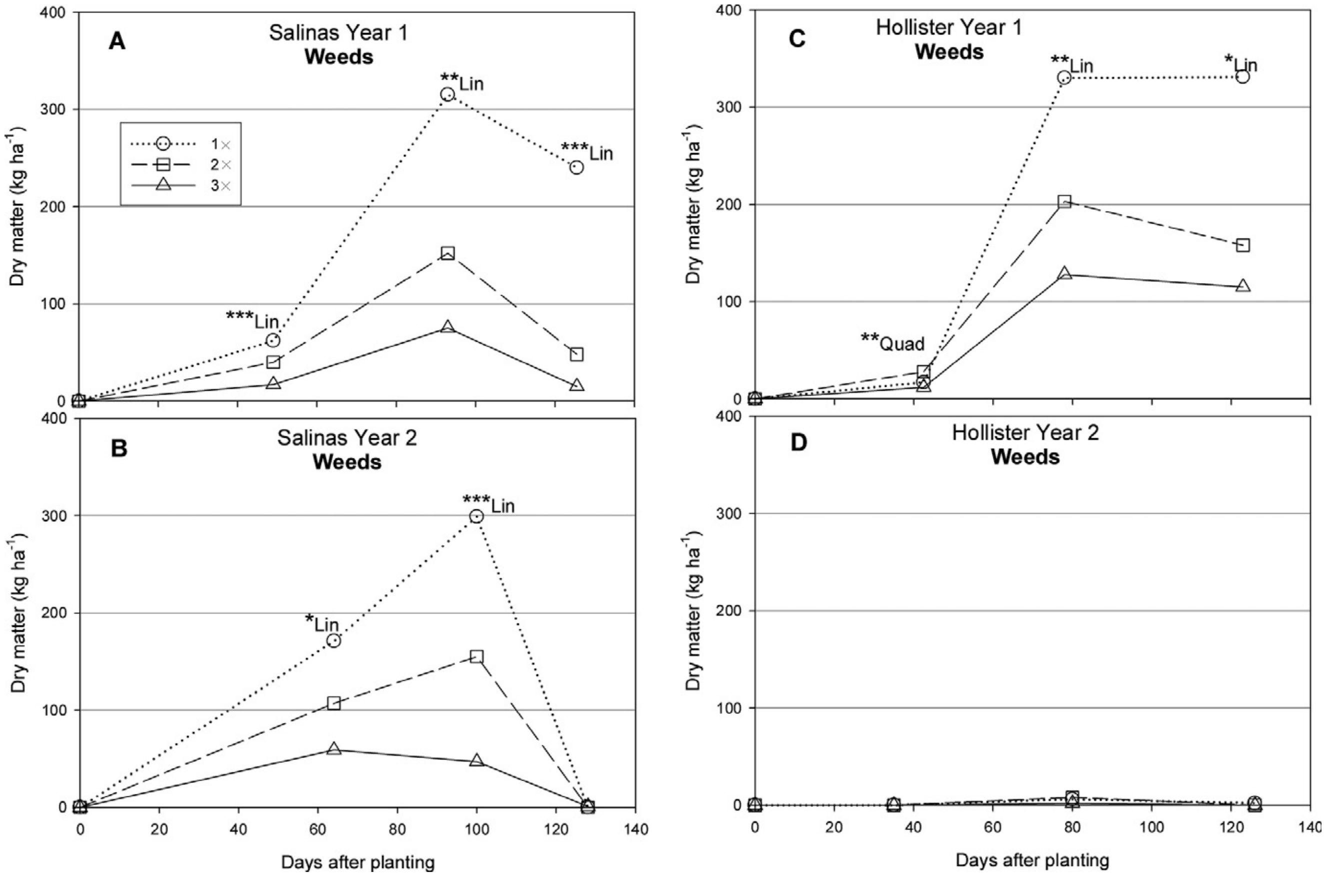

Fig. 2. Relationship between days after planting and weed dry matter (DM) in a legume-oat cover crop at three seeding rates (1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, 3× = 336 kg ha^{-1}) on three harvest dates in Salinas (A, B) and Hollister (C, D), CA, during Year 1 (2003–2004) and Year 2 (2004–2005). The significance of seeding rate on weed DM is shown for harvest dates with significant linear (Lin) and quadratic (Quad) effects where *, **, and * are significant at the $P \leq 0.05$, 0.01, and 0.001 levels, respectively.**

($P < 0.001$) and quadratically ($P < 0.05$) with SR from 12 to 28 to 36% in Year 1, and also increased linearly ($P < 0.001$) with SR from 7 to 13 to 20% in Year 2 for the 1×, 2× and 3× rates, respectively. The significant SR × year interaction ($P < 0.001$) indicated that rate had more of an effect on ground cover in Year 1 than Year 2. Ground cover was probably greater in Year 1 because of the earlier planting date, warmer fall conditions, and increased age of plants when the ground cover measurements were taken. The greater weed suppression by the higher SRs (discussed below) was likely due to the increased early-season ground cover. Increasing planting density and reducing row spacing can reduce the photosynthetic photon flux density at the soil surface and improve crop competitive ability (Blackshaw et al., 1999; Mohler, 2000; Teasdale, 1995). Brennan and Smith (2005) reported large differences in early-season ground cover in a legume-oat mix (19%), oat (29%), and mustard (*Brassica* spp.) (79%) cover crops that affected their competitive ability with weeds.

Weed Density and Species

Early-season weed emergence was unaffected by cover crop planting arrangement or SR in Hollister. This agrees with a previous study using mustard, a legume-oat mix, and oat cover crops (Brennan and Smith, 2005). Weed densities in Hollister were significantly greater in Year 1 (125 plants m^{-2}) than Year 2 (7 m^{-2}) averaged across rates and planting arrangements ($P < 0.001$). Weed density was not measured in Salinas, but the density in a simultaneous winter cover crop trial in an adjacent field with the same management history was 180 plants m^{-2} (Brennan, unpublished data, 2003). The common weeds were *Malva parviflora* L., *Capsella bursa-pastoris* L., *Stellaria media* L., *Lamium amplexicaule* L., *Urtica urens* L., and *Sonchus* spp. in Hollister, and *M. parviflora*, *C. bursa-pastoris*, *S. media*, *L. amplexicaule*, *Sonchus* spp, and *Poa annua* in Salinas. Weed emergence in Hollister was probably lower in Year 2 than Year 1 because a shallow cultivation was necessary to remove weeds that germinated after an early fall storm in late October 2004 just before the Year 2 planting. This cultivation created a stale seedbed (Boyd et al., 2006); however, this scenario is unusual before cover cropping.

Weed Dry Matter

Weed DM was affected significantly by harvest date, year, and SR at both sites (Table 1). We accept our hypothesis that weed suppression would increase with SR because, when weeds were abundant (i.e., Year 1 in Hollister, and both years in Salinas), weed DM decreased linearly with increasing SR between 40 and 100 DAP (Fig. 2). During these years, weed DM in the least suppressive SR (1×) peaked at approximately 300 kg ha^{-1}, which is considerably less than the 1750 kg ha^{-1} previously reported with a similar mix (Brennan and Smith, 2005). Weed DM at both sites increased from planting until approximately half way through the cover cropping period and declined thereafter, as in Brennan and Smith (2005); this decline typically

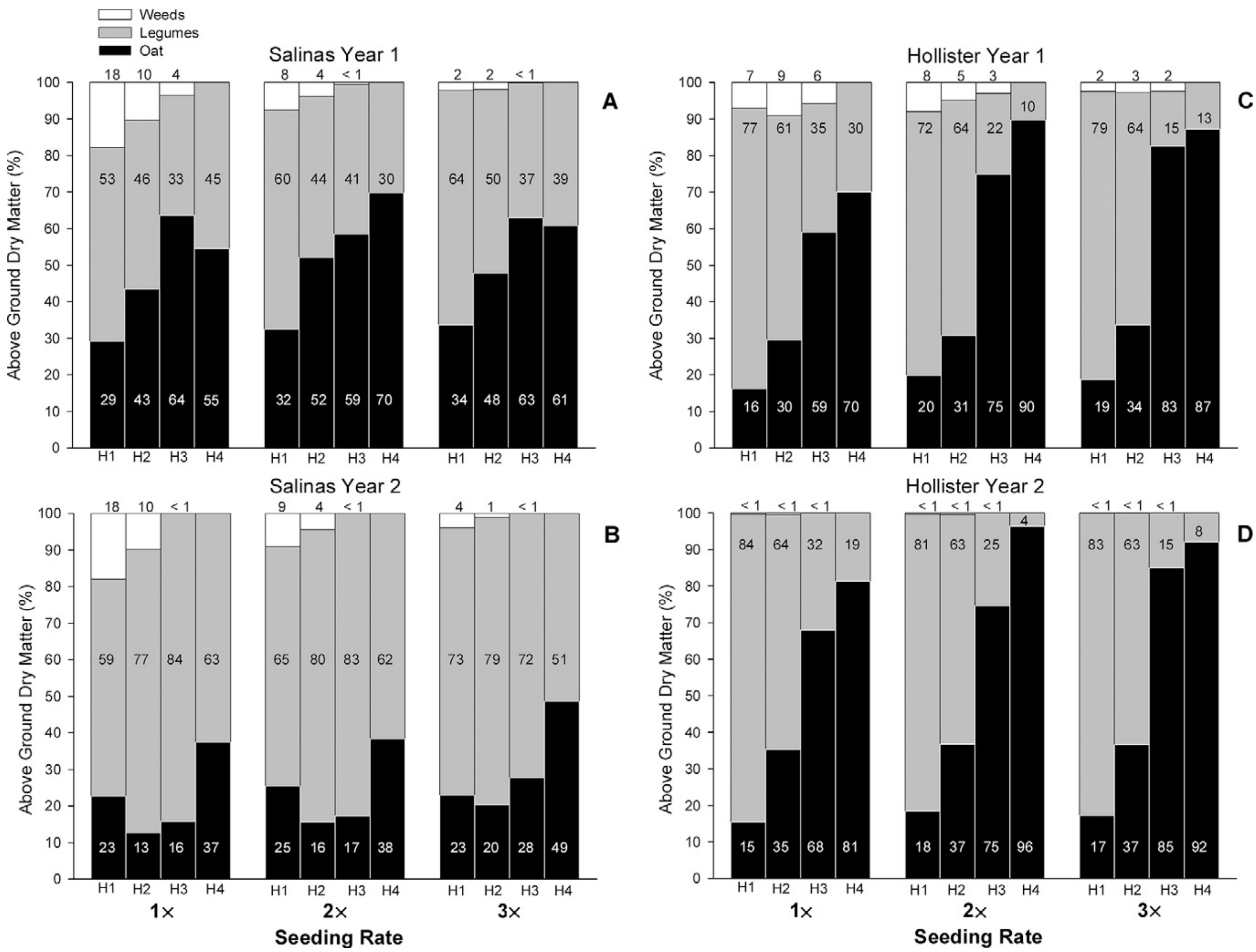

Fig. 3. Percentage of aboveground dry matter (DM) from weeds, legumes, and oat in Salinas (A, B) and Hollister (C, D) at three seeding rates (1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, 3× = 336 kg ha^{-1}), over four harvests (H1 to H4) during Year 1 (2003–2004) and Year 2 (2004–2005). Weed DM was only measured during the first three harvests each year and is indicated in the numbers above each bar.

occurs after weed seed production. The percentage weed DM of total aboveground DM was usually highest at Harvest 1 and declined with increasing rate and with each harvest (Fig. 3). At Harvest 1, the percentage of aboveground DM from weeds was about twice as high in Salinas both years as in Year 1 in Hollister.

It is reasonable to assume the reduction in weed DM at the higher SRs at both sites in our study reduced weed seed production. Previous studies in the region reported less weed seed production in cover crop treatments with less weed biomass (Boyd and Brennan, 2006; Brennan and Smith, 2005). For example, Boyd and Brennan (2006) reported 93% less weed seed production by *C. bursa-pastoris* when weed DM was reduced by blind cultivation from 727 to 169 kg ha^{-1}; blind cultivation is shallow cultivation with an implement such as a rotary hoe without regard to crop row position. Increasing the SR is often a more dependable way than blind cultivation to suppress weeds in a winter cover crops because blind cultivation is only effective during dry fall periods after cover crop germination.

Studies with winter cover crop mixes from other regions have seldom reported weed DM in the cover crops, or have only reported weed DM in unmanaged fallow treatments (Clark et al., 1994; Odhiambo and Bomke, 2001; Ranells and Wagger, 1997; Sainju et al., 2005). Reports of weed DM from other regions are more common in cover crop mixes grown in the spring and summer (Akemo et al., 2000; Creamer and Baldwin, 2000). In vegetable systems in the central coast of California, weed growth in any season is problematic because crop production occurs during all seasons. Furthermore, some common weeds (i.e., *U. urens*, *C. bursa-pastoris*, *M. parviflora*) grow year-round due to the cool, coastal climate. Weed DM production in winter fallow fields is extremely low because weeds that germinate in fallow fields are killed with shallow cultivation, flaming, or herbicides as the weather permits.

Cover Crop Dry Matter Production and Component Dynamics

Dry matter production by the legume, oat, and total cover crop (legume + oat) differed significantly between year, rate, and harvest at both sites (Table 1). In most cases, DM of the total cover crop and the legume and oat components increased linearly with SR during the first 100 DAP (Fig. 4, 5, 6). The SR had no effect on total cover crop DM or legume DM at the end of the season at either site; however, SR had a significant linear and quadratic effect on oat DM in Hollister during Year 1 at the end of the season. In Hollister, total cover crop DM

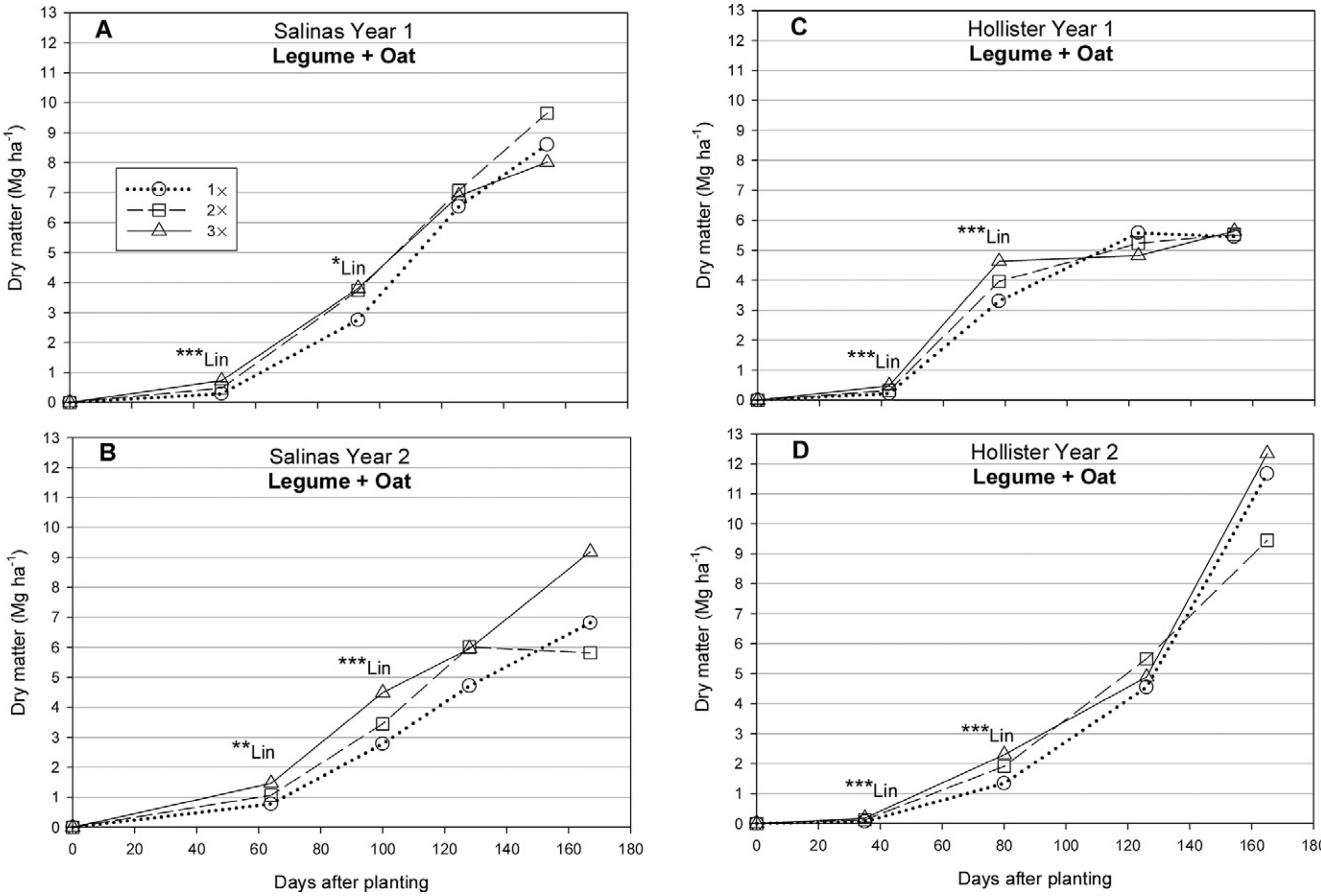

Fig. 4. Relationship between days after planting and total cover crop (legume + oat) dry matter (DM) of a legume-oat cover crop at three seeding rates (1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, 3× = 336 kg ha^{-1}) on four harvest dates in Salinas (A, B) and Hollister (C, D), CA, during Year 1 (2003–2004) and Year 2 (2004–2005). The effect of seeding rate on total cover crop DM is shown for harvest dates with significant linear (Lin) effects where *, **, and * are significant at the $P \leq 0.05$, 0.01, and 0.001 levels, respectively; quadratic effects were not significant for any harvest.**

production was approximately twice as high in Year 2 (9–12 Mg ha^{-1}) as Year 1 (5.5 Mg ha^{-1}); however, it was relatively similar (7–8 Mg ha^{-1}) across years in Salinas (Fig. 4). A previous study with a winter cover crop of 10% oat and 90% legumes in Salinas reported total cover crop yields of 5 to 10 Mg ha^{-1} (Brennan and Smith, 2005). The higher cover crop DM production during Year 2 in Hollister was most apparent after 80 DAP and may have been due to less weed pressure, higher rainfall, and cooler spring conditions that year.

The contribution of the legume and oat components to the total cover crop DM after 100 DAP varied markedly between sites. Averaged across SRs, legume DM reached 3 to 5 Mg ha^{-1} in Salinas compared with Hollister, where it was usually below 3 Mg ha^{-1} (Fig. 5). Furthermore in Salinas, although SR did not affect legume DM after 100 DAP, legume DM continued to increase through the season. In contrast, legume DM in Hollister usually declined after 100 DAP, and in Year 1 it declined linearly with increasing SR at 123 DAP (Harvest 3). As with legume DM, oat DM increased linearly with SR early in the season, and this pattern often continued though the remainder of the season. Averaged across SRs, oat DM was highest (8–10 Mg ha^{-1}) in Hollister in Year 2, but highest (4–6 Mg ha^{-1}) in Year 1 in Salinas (Fig. 6).

The percentage of total aboveground DM from cover crop components varied with harvest date, year, and SR (Fig. 3). For example, averaged across years and rates in Hollister, legume DM comprised 79% of the total aboveground DM at the first harvest, but only 14% at the final harvest. The percentage legume DM declined while the percentage oat DM increased over time at both sites, although this pattern was most apparent in Hollister and indicates that the legumes were less competitive with oat in Hollister than in Salinas. With the exception of Year 1 in Hollister, most of the total cover crop DM production occurred during the second half of the cover cropping period. For example, in Salinas, approximately 75% of the total cover crop DM production occurred after 78 DAP in Year 1. The relatively small increase in cover crop DM from 78 to 154 DAP may be due to the relatively warm and dry conditions in Hollister in Year 1 (Fig. 1). We speculate that the differences in DM production by the legume and oat components between sites were due primarily to differences in soil and possibly climate between sites. The Hollister farm is considered a higher fertility site due to its higher soil organic matter (3–5%) versus Salinas (1.2%), and more than 10 yr of intensive vegetable production in Hollister. The higher fertility soil in Hollister may have increased the competitive ability of the oat component relative to the legume. Ranells and Wagger (1997) found that hairy vetch produced more DM in a mixture with rye under low than high soil residual N levels.

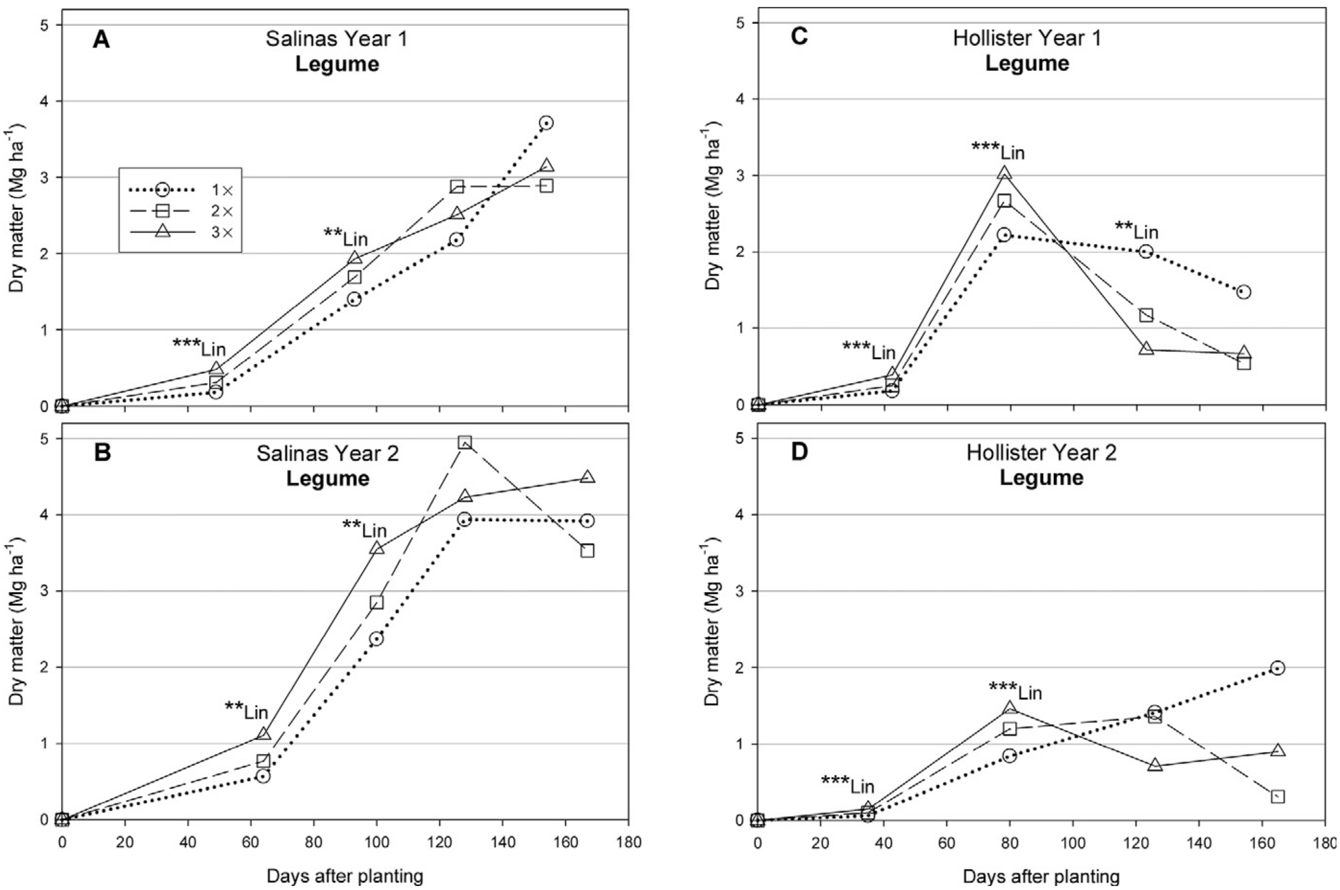

Fig. 5. Relationship between days after planting and legume dry matter (DM) production in a legume-oat cover crop at three seeding rates (1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, 3× = 336 kg ha^{-1}) on four harvest dates in Salinas (A, B) and Hollister (C, D), CA, during Year 1 (2003–2004) and Year 2 (2004–2005). The effect of seeding rate on legume DM is shown for harvest dates with significant linear (Lin) effects where **, and * are significant at the $P \leq 0.01$, and 0.001 levels, respectively; quadratic effects were not significant for any harvest.**

Few studies with cover crop mixes have tracked the dynamics of legume and grass DM through the season. Vetch DM in a wheat–vetch mix planted in September in British Columbia increased from 12% in March to 21% in April (Odhiambo and Bomke, 2001). Ranells and Wagger (1997) also reported that vetch and clover DM increased in mixes with rye from December to April. Whereas in our study, the legume DM ranged from 64 to 83% of the total cover crop DM at the first sampling, and declined through the season (Fig. 3). The suppression of legumes by the cereals is more typical in intercropping studies (Ofori and Stern, 1987).

Interpreting the dynamics of cover crop DM production is complicated when the DM of one component declines during the season as with the legume in Hollister. In such cases, the end-of-season DM of the legume + oat components underestimate the total DM production during the season, and a more accurate measure of the total season DM production would be to add the maximum legume DM to the maximum oat DM. For example, with the 3× rate in Year 1 in Hollister, the maximum legume (3 Mg ha^{-1}, Fig. 5) plus the maximum oat DM (4.6 Mg ha^{-1}, Fig. 6) is 7.6 Mg ha^{-1}, which is 36% higher than the total end-of-season cover crop DM (5.6 Mg ha^{-1}, Fig. 4) for this treatment. The decline in legume DM in Hollister after midseason was likely caused by leaf senescence and plant mortality due to competition from the oat. The competitive effects of oat on the legume DM in Hollister were most apparent at the 2× and 3× rates (Fig. 5).

Practical Implications

It is important to consider if the benefits of planting a cover crop at higher SRs are worth the increased cost of the seed. Few studies have addressed SR issues with cover crops, but recommended SRs for a vetch-rye mix were based on the performance of the cover crop and subsequent corn cash crops, as well as seed costs (Clark et al., 1994). This approach is appropriate, and the optimal rate would likely differ between regions and production systems due to differences in production costs and profit margins. In the central coast of California, cover crop seed accounts for a relatively small percentage (i.e., 10–20%) of the total cost of cover cropping, considering all operations involved with cover cropping such as field preparation, irrigation before winter rainfall, land rent, and tillage at the end of the cover cropping period (Tourte et al., 2004). For example, the estimated cost of cover cropping in the Salinas area is currently more than \$800 ha^{-1}. Tripling the SR with a legume cereal mix that typically costs \$1 kg^{-1} would only increase the cost of cover cropping by about 13% (Brennan and Tourte, unpublished data, 2007). This cost is minimal compared with the production costs of \$17,000 ha^{-1} for organic lettuce in this region (Tourte et al., 2004).

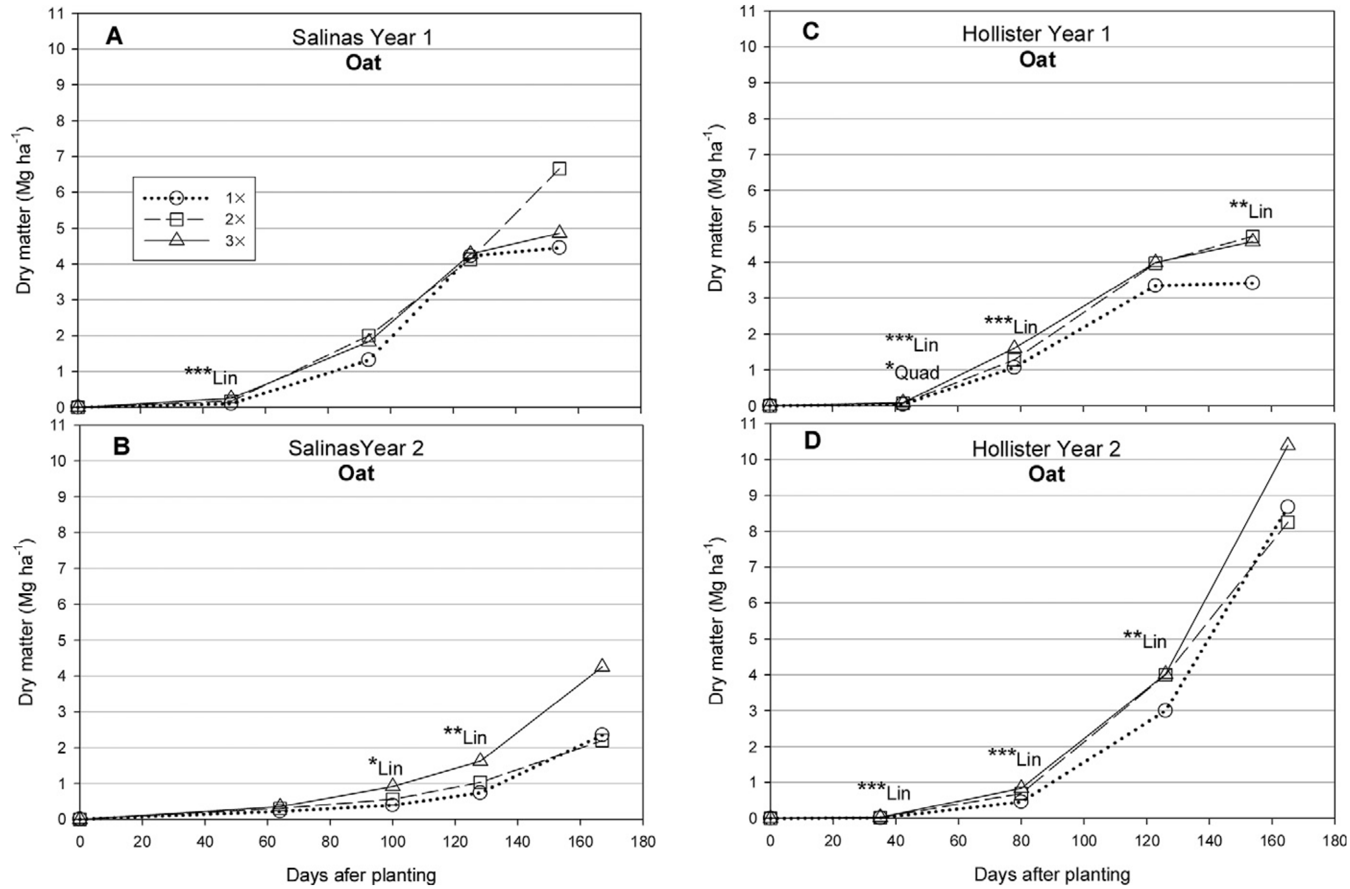

Fig. 6. Relationship between days after planting and oat dry matter (DM) production in a legume-oat cover crop at three seeding rates (1× = 112 kg ha^{-1}, 2× = 224 kg ha^{-1}, 3× = 336 kg ha^{-1}) on four harvest dates in Salinas (A, B) and Hollister (C, D), CA, during Year 1 (2003–2004) and Year 2 (2004–2005). The effect of seeding rate on oat DM is shown for harvest dates with significant linear (Lin) and quadratic (Quad) effects where *, **, and * are significant at the *P* ≤ 0.05, 0.01, and 0.001 levels, respectively.**

Determining the optimal SR in a mixed cover crop is more complex than with cash crops or with monoculture cover crops. Cash crop SRs are usually selected to optimize the yield and quality of the harvested product. The SR choices for cover crops are more complex because it is difficult to assign economic value to DM that is used for mulch or soil improvement, and for cover crop services (i.e., nitrate scavenging, erosion control, weed suppression, N fixation, diversity). For example, if the main objective of cover cropping is to maximize biomass production by the end of the winter for soil improvement, the 1× rate would be most cost effective because final biomass production was unaffected by rate. Whereas the 3× rate would be optimal to suppress weeds that could contribute to the weed seed bank. The SR selection in legume-grass cover crop is further complicated because rate affects competition between components and thus may impact N fixation. A primary reason to include legumes in mixed cover crops in our region is to promote biological N fixation that, in theory, may reduce the need for supplemental N fertilizers in subsequent vegetable crops. The importance of N fixation in the legumes in the study is not known because N fixation was not quantified. However, in legume-grass mixtures, N fixation was inhibited as soil N increased and the grass component became more dominant (Ledgard and Steele, 1992; Munoz and Weaver, 1999). The consistent dominance of the oat over the legume component in Hollister suggests that conditions favored the oat and that N fixation by the suppressed legume component was probably minimal. In such cases, using a nonlegume cover crop such as cereal rye, with good weed suppression and N scavenging ability, may be a more cost-effective way to add soil organic matter, suppress weeds, and improve the N budget for the farm. While N leaching is generally less on organic than conventional systems (Kirchmann and Bergstrom, 2001; Stopes et al., 2002), leaching may be an issue in high-value organic vegetable systems that typically use supplemental organic fertilizers.

CONCLUSIONS

This study showed that planting arrangement had no effect on cover crop growth or weeds in a legume-oat mixture. However, increasing the typical SR from 112 kg ha^{-1} to 336 kg ha^{-1} hastened early-season ground cover and cover crop DM accumulation, but did not affect final DM of the cover crop. The competition caused by the increasing SR consistently reduced the weed biomass by severalfold when weeds were abundant. The legume component was probably responsible for most of the early-season weed suppression from increasing SR because legume DM dominated during that period. Competition dynamics and DM production by the legume and oat components in this study varied considerably through the season within and between sites and year. Legume DM production was more stable across years and sites than oat DM, indicating that most of the variation in total cover crop DM production was due to changes in the growth of the oat component. The percentage of legume DM of total aboveground DM was greatest early in the season and declined through the season.

The results of this study are applicable to both organic and conventional vegetable farms that are trying to maximize cover crop biomass production and minimize weed growth, especially in regions where year-round weed management is important. More research is needed (i) to understand how soil quality, soil moisture, and mixture composition affect the complex competition dynamics in mixed cover crops, and (ii) to design mixes that consistently suppress weed growth yet improve N use efficiency in high-value vegetable production systems. It is unclear if the potential benefits of N fixation by legumes can be achieved in a mix that is planted at a high enough density to provide ample weed suppression. In future studies with legume-cereal mixes it would be useful to measure soil residual N levels at the cover crop planting date, N fixation, and seasonal changes in N content of the cover crop components. Such information may help to explain differences in DM production by the legume and cereal components, and determine optimal kill dates for the cover crop.

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Seeding Rate and Planting Arrangement Effects on Growth and Weed Suppression of a Legume–Oat Cover Crop for Organic Vegetable Systems

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Agron. J. 101:979–988 (2009)

The growing degree days(GDD) values shown in the original Fig. 1 were mistakenly calculated in °F with a baseline threshold of 39°F. The corrected figure here shows them calculated in °C with a baseline threshold of 4°C using the online calculator at the University of California Statewide Integrated Pest Management (http://www.ipm.ucdavis.edu).

The authors regret the errors and apologize for any inconvenience this may have caused readers.

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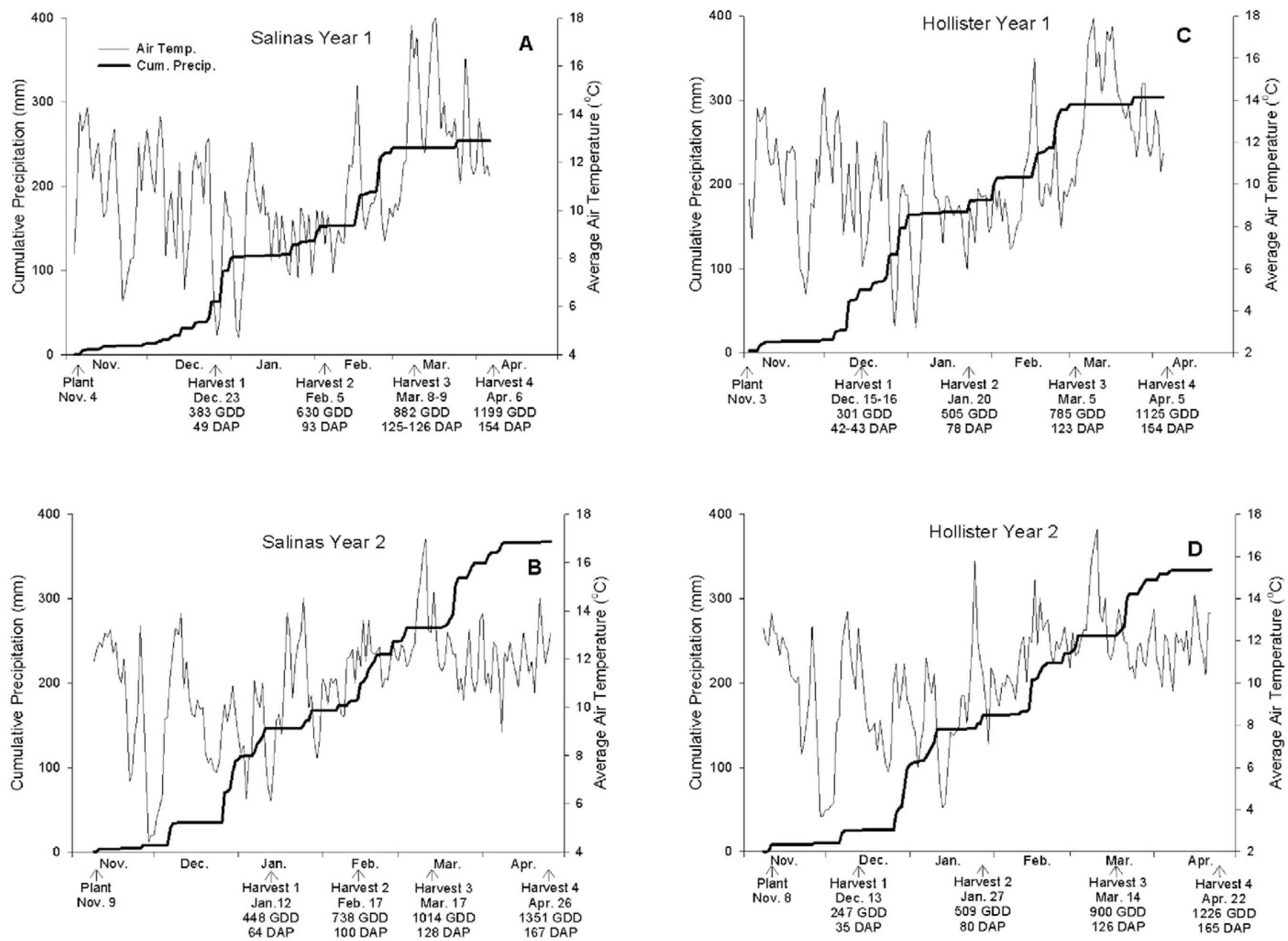

Fig. 1. Cumulative precipitation and daily average air temperature from the California Irrigation Management Information System in Year 1 (2003–2004) and Year 2 (2004–2005) at Salinas (A, B, Station 89) and Hollister (C, D, Station 126) available at http://wwwcimis.water.ca.gov [verified 13 Apr. 2009]. The 13-yr average rainfall between November and April (1993–2007) was 395 mm (Hollister) and 346 mm (Salinas). Dry matter harvest dates, growing degree day (GDD) accumulation, and days after planting (DAP) are indicated for each site and year. The GDD were calculated with the single sine method with a baseline threshold of 4°C using the online calculator at the University of California Statewide Integrated Pest Management web site, http://www.ipm.ucdavis.edu [verified 13 Apr. 2009].