ORGANIC FARMING RESEARCH FOUNDATION

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This is a final project report submitted to the Organic Farming Research Foundation

Project Title:
The effect of cover crop seeding rate, planting arrangement, and mixture composition on cover crop performance and weed management on organic vegetable farms on the central coast of California

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1. PROJECT SUMMARY

Cover crops are key components of crop rotations on organic farms in the central coast of California and affect soil quality, nutrient cycling, and pest and disease management. Many organic farmers in this region cover crop each field every 1 to 3 years. Common cover crops in the area include monocultures of cereals or mustards, and mixtures of cereals and legumes. To optimize cover crop benefits, organic farmers need more information on how seeding rate, planting arrangement, and mix composition affect cover crop biomass production and weed suppression.

The research described here focused on the effects of cover crop seeding rate, planting arrangement, and mix composition on cover crop biomass production and weed suppression during the winter cover cropping period on organic cool season vegetable farms on the central coast of California. The research occurred on two commercial organic farms and the on USDA-ARS certified organic research farm between October 2003 and April 2005 and included five trials.

Trials 1 to 3 evaluated weed and cover crop growth of rye and a legume/oat mixture planted at three seeding rates in a one-way versus grid planting arrangement. Weed suppression increased with increasing seeding rate. Cover crop biomass production was higher early in the season at the higher seeding rates but final biomass production was not affected by seeding rate. Planting arrangement did not affect weed or cover crop growth of the legume/oat mixture. However, rye biomass was higher and weed biomass was lower in the grid planted rye cover crop during one year.

Trials 4 and 5 evaluated weed and cover crop growth of several monoculture cover crops and 17 mixtures of legumes, oat, rye and mustard. Cover crop biomass production was usually higher in nonlegume than in legume monocultures, and weed biomass was usually less in the nonlegume monocultures. Biomass production and weed suppression by the mixes varied considerable between years and sites. In the first year, weed biomass was in order of legume/oat>legume/rye>legume/mustard at both sites, but this pattern did not occur in the second year. Increasing the non-legume proportion in a mixture usually increased weed suppression but also reduced growth of the legume component. More research is needed to better understand the complex competition dynamics in cover crop mixes to develop mixes that scavenge nitrogen, suppress weeds, but also allow adequate growth and nitrogen fixation by the legume component.

The results of these trials were communicated to farmers and the general public in field days and presentations. The information from this research will help farmers to optimize the benefits of cover crops and reduce weed management costs in subsequent vegetable crops.

2. INTRODUCTION

Cover crops are key components of crop rotations on organic farms in the central coast of California and affect soil quality, nutrient cycling, and pest and disease management. Many organic farmers in this region cover crop each field every 1 to 3 years. Common cover crops in the area include monocultures of cereals or mustards, and mixes of cereals and legumes. To optimize cover crop benefits, organic farmers need more information on how seeding rate, planting arrangement, and mix composition affect cover crop biomass production and weed suppression.

Weed management is one of the most critical yield-limiting factors in organic production systems in California (Clark et al., 1999; Gaskell et al., 2000). Weed control is difficult and expensive on organic vegetable farms in the central coast and often costs between $500 and $1,300/acre/crop. Organic farmers need practical information to help minimize weed seed production during all stages of crop rotation. Weed growth in winter cover crops on the central coast can cause problems because many weed species occur year round and therefore weed seed produced during the winter will likely increase weed management costs in subsequent cash crops. Reducing weed seed production during the cover cropping period has received little research attention. Large amounts of weed seed production (13,000 weed seeds/m^2) can occur during the cover cropping period (Brennan and Smith, 2005). This suggests that cover cropping is a weak link in the weed management programs on organic farms in the area, and that there is a need for research to minimize weed seed production during the cover cropping period. Weed growth and weed seed production are negatively correlated with crop competitive ability. The competitive ability is mainly determined by seeding rate, planting arrangement, planting date, and cultivar (Mohler, 2000). Factors affecting cover crop competitive ability have received little research attention.

Seeding rates have been extensively studied in cash crops and are shown to affect yield, canopy closure, and weed growth and seed production (Ball et al., 2000; Blackshaw et al., 1999; Champion et al., 1998; Doll et al., 1995; Lopez-Bellido et al., 2000; Radford et al., 1980; Shield et al., 2002; Teasdale, 1995; Teasdale, 1998; Weiner et al., 2001; Widdicombe and Thelen, 2002). Neighboring plants compete for light, nutrients and water earlier in the season as plant density increases (Harper, 1977). Few studies (Akemo et al., 2000; Clark et al., 1994) have determined optimal seeding rates for cover crop mixes. Recommended rates for cover crops are extremely broad (Ingels, 1998; Miller et al., 1989; SAN, 1998) and generally are based on recommendations for grain and forage production (Stoskopf, 1985). However, it is unlikely that seeding rates for grain and forage production are optimal for cover crops because the goals and management of cover crops are different.

Plant arrangement is another factor that can be manipulated to reduce weed growth. Reducing row spacing and increasing planting uniformity can increase yield and reduce weed growth (Buchanan and Hauser, 1980; Marshall and Ohm, 1987; Mohler, 2000; Roberts et al., 2001; Weiner et al., 2001; Welch et al., 1966). A simple way to increase planting uniformity is to plant rows in perpendicular directions in a grid pattern at half the seeding rate that would be used to plant the one-way direction (Ball et al., 1997; Olsen et al., 2005a; Olsen et al., 2005b; Weiner et al., 2001).

Cropping systems where mixes of different plants are grown simultaneously on the same area are referred to as intercropping (Willey, 1979). Intercropping is more complex than monocropping, and may provide several benefits over monocropping including (1) higher yields (Willey, 1979), (2) greater yield stability (Liebman and Staver, 2000), (3) more efficient use of resources (Trenbath, 1986), and (4) improved pest and disease management (Altieri, 1986). There is considerable research on intercropping systems where the component crops produce food or fodder (Francis, 1986; Haynes, 1980), but little research on intercropping systems where component crops are not harvested as occurs with mixed cover crops. This lack of research is surprising considering the popularity and frequent mention of cover crop mixes in extension publications (Ingels et al., 1998; SAN, 1998). Cover crop mixes of legumes (*Vicia* spp. and peas) and cereals (oats and rye) are common in organic vegetable production systems in the central coast of California. Research on cover crop mixes elsewhere in the U.S. compared mixes with monocultures and focused on dry matter production and soil nitrogen dynamics during the cover cropping period and during subsequent cash crops (Burket et al., 1997; Odhiambo and Bomke, 2001; Ranells and Wagger, 1997a; Ranells and Wagger, 1997b; Rosecrance et al., 2000), but seldom has evaluated weed suppression (Akemo et al., 2000; Creamer et al., 1997).

This report describes five trials that investigated the effects of cover crop seeding rate, planting arrangement, and mixture composition on cover crop biomass production and weed suppression during the winter cover cropping periods from the fall of 2003 to the spring of 2005.

3. OBJECTIVES

(1) To determine the effect of cover crop seeding rate and planting arrangement on cover crop biomass production, cover crop canopy development, and weed suppression. Seeding rates included a standard rate (1x) typical on farms in the area, and higher rates (2x, 3x). Plant arrangements included a one-way versus a grid drilling pattern. This was the objective of trials 1 to 3.

(2) To determine cover crop biomass production, canopy development, and weed suppression of 17 cover crop mixes. These mixes included several commercially available mixes of legumes and cereals, and novel mixes of legumes, cereals and mustards. This was the objective of trials 4 and 5.

(3) To demonstrate the effects of cover crop seeding rate, planting arrangement, and mixture composition on cover crop performance and weed suppression during annual field days for farmers on the central coast of California.

4. MATERIALS AND METHODS

Experimental Sites

The trials occurred at three certified organic farms including Phil Foster's farm with a Clear Lake Clay soil in Hollister, a Tanimura & Antle farm managed by Ron Yokota with a Salinas Clay Loam soil in Salinas, and the USDA-ARS organic research farm with a Chualar Loamy Sand in Salinas. These sites were chosen to reflect a range of climatic conditions and soil characteristics that are typical of organic farms in the region. All three sites have been certified by California Certified Organic Farmers for several years. In this report, year 1 refers to the 2003-2004 cover cropping period and year 2 refers to the 2004-2005 cover cropping period. High-value vegetables were grown in the fields just prior to planting all trials each year, except for at the USDA-ARS site where a buckwheat cover crop was the prior crop in year 1. The trials occurred on different fields at each site during each of the two years.

Planting Equipment

Precise control of seeding rate was essential in these trials and was achieved with a state-of-the-art 15' wide research grain drill from the USDA-ARS organic research program (Photographs 1 and 2). Pre-weighed packets of seed were manually added to 4 seed cones that dispersed the seed to 28 seed lines with 6" (15 cm) spacing as the drill crossed over each plot. The drill was attached to a tractor provided by the cooperating farmer at each site.

Field preparation and cover crop management

Field preparation included discing and harrowing as necessary. Sprinkler irrigation was applied as needed after seeding to establish the cover crop. At the end of the cover cropping period (February to April) the cover crops were flail mowed and incorporated into the soil.

Seeding Rate and Planting Arrangement (Trials 1-3)

These trials are summarized in Table 1. Trial 1 with rye and trial 2 with the legume/oat mixture evaluated three seeding rates and two planting arrangements. The evaluation of planting arrangement required considerably more space than was used for the actual treatment plots (12.2 m x 12.2 m; 40' x 40') due to the need for adequate turning area between plots (Figure 1). The plot layout for trials 1 and 2 covered approximately 1.2 ha (3 acres). Trial 3 used the same cover crop mixture as in trial 2, but focused on seeding rate with plots that were 1.2 m (40') wide and 15.2 m (50') long and covered 0.24 ha (0.6 acres). All 3 trials were replicated 4 times in a randomized complete block design.

Cover crop population density was determined by counting the number of cover crop plants in three 50 x 50 cm quadrants at approximately 1 month after planting. Above ground biomass of cover crops and weeds was determined by harvesting biomass in 100 x 50 cm, or 50 x 50 cm quadrants at the harvest dates in Table 1. The biomass samples were oven dried at 65° C for at least 48 hours until the weight had stabilized. Harvested biomass from trials 2 and 3 were separated into the legume and oat components prior to drying. The last harvest date at both sites occurred after most cover crops had flowered but prior to setting viable seed. Cover crop canopy development was determined by holding a 30 x 30 cm quadrat with 64 cross grids approximately 50 cm above the ground and counting the number of grid crosses that were over cover crop vegetation. These values were converted to percent ground cover.

Cover Crop Mixes (Trials 4 and 5)

The cover crop mix trials occurred at the Hollister site (Trial 4), and at the USDA-ARS site (Trial 5) in Salinas in the same fields as trials 2 and 3. Mixes included 17 combinations of the nonlegumes (oat, rye, mustard) and legumes (bell bean, pea, vetches) and are described in table 2. Rye, oat, mustard, and the legume components were also evaluated as monoculture cover crops. Thus, a total of 25 cover crops were evaluated in trial 4 and 5. A randomized complete block design with 4 replicates was used in each trial. Each treatment plot was 2.1 m (7') wide and 9.1 m (30') long, and each trial covered a 0.16 ha (0.4 acre) area. The majority of the mixes evaluated were novel combinations. Trial 4 was planted in Hollister on November 3, 2003 and November 8, 2004. Trial 5 was planted in Salinas on November 4, 2003 and November 9, 2004.

Measurements of cover crop density, ground cover, and aboveground cover crop biomass were done as described in trials 1 to 3. Cover crop biomass was harvested 2 times each year in trials 4 and 5. Weed biomass was only determined at the first of two harvests of cover crop biomass in each trial.

Statistical Analysis

Data analyses of trials 1-3 were conducted with the MIXED and GLM procedures in SAS version 9.1 (SAS Inst. Cary, NC) for each trial separately. The data were transformed as needed to meet the assumptions of analysis of variance, but untransformed means are presented. In all analyses, significance is determined at the $p \leq 0.05$ level. Statistical analysis of data from the mixed trials 4 and 5 was complicated by the large number of treatments and the lack of homogeneity of the variance for each response variable. Therefore in this report only means and standard errors for the mixes data are presented. Statistical differences between the cover crops in trials 4 and 5 will be determined following consultations with a statistician and will be reported when these data are reported in a future peer-reviewed publication.

5. RESULTS AND DISCUSSION

The results presented here summarize the major results from the five trials, however, more detailed descriptions and analyses of each trial will be reported in peer-reviewed publications. Copies of the peer-reviewed publications from these trials will be submitted to OFRF when they have been published and will also be available upon request from Eric Brennan.

Climate

The rainfall during the cover cropping periods was higher in year 2 than year 1 at both sites, and lower than the 13 year average in Hollister (395 mm, 15.6”) both years, and in Salinas (346 mm, 13.6”) in year 1 (Figure 2). Rainfall distribution varied between and within years. Monthly winter rainfall usually peaks at about 85mm (3.3”) in January but in year 1 less than half of this occurred. Only 15 mm (0.6”) of rain occurred in March of year 1 at both sites, versus 93 mm (3.7”) in Salinas and 87 mm (3.4”) in Hollister in year 2. The more frequent and later season rainfall pattern that was most apparent in year 2 in Salinas may explain differences in cover crop biomass production discussed below. Accumulated growing degree days (GDD) through the season differed between sites, and harvests within year. In Salinas, there were on average 200 GDD more at each harvest in year 2 than year 1.

Planting Arrangement (Trials 1 and 2)

Under the field conditions in trials 1 and 2, planting in a grid pattern was more difficult than planting in the one-way pattern because of the need to drive slower to avoid excessive bouncing as the tractor crossed over the wheel tracks from the first planting direction. With the rye cover crop (trial 1), planting arrangement had a significant effect on rye biomass production and weed suppression in year 2 (2004-2005) but not in year 1 (2003-2004). In year 2 and across all seeding rates, rye biomass production was higher in the grid planting pattern (1.4 Mg/ha, 0.6 t/a) than in one way pattern (1.1 Mg/ha, 0.5 t/a) at harvest 1, and was also higher in the grid pattern (7.8 Mg/ha, 3.5 t/a) than one way pattern (6.2 Mg/ha, 2.8 t/a) at the final harvest. In contrast, planting arrangement had no effect on cover crop biomass production or weed suppression with the legume/oat mixture in trial 2.

Studies elsewhere have reported improved weed suppression, higher grain yields, and higher crop biomass production in wheat planted in a grid versus a one-way pattern (Olsen et al., 2005a; Olsen et al., 2006; Olsen et al., 2005b; Weiner et al., 2001). It is unclear why the effect of planting arrangement on rye biomass production and weed suppression was not consistent across years, however it may be related to the differences in weed pressure between years. We speculate that planting arrangement did not affect cover crop or weed growth in the legume/oat mixture (Trial 2) because the diversity in canopy and root architectures in the mixed cover crop cancelled any potential benefits from increased spatial uniformity.

Although grid planting improved weed suppression in a rye cover crop in one year, increasing the seeding rate in the one-way planting is probably a more cost effective and beneficial way to improve weed suppression than grid planting at a lower rate. Grid planting requires twice as many passes over a field as the normal one-way pattern and thus increases fuel use, labor costs, driver fatigue, planting time, tractor maintenance costs, soil compaction and dust production. Agricultural dust creates health and environmental problems, and increased operations for cover cropping in the fall can increase dust production even when cover crops are planted in the normal one-way pattern (Baker et al., 2005).

Cover crop seeding rate effects on weeds (Trials 1-3)

It is interesting to note differences in maximum weed biomass between the sites where the trials were conducted that ranged from less than 20 kg/ha (18 lb/a) to more than 350 kg/ha (312 lb/a) (Figures 3, 4, 5). The USDA-ARS organic research farm in Salinas produced the most weed biomass across years (Figure 5), followed by the Hollister farm where weed biomass was high in year 1 and low in year 2 (Figure 4), and finally by the Tanimura & Antle farm in Salinas where weed biomass was low in year 1 and moderate in year 2. These differences are the result of the weed seed bank and differences in field preparation prior to the cover crop that affected weed emergence. For example, weed emergence in Hollister was probably lower in year 2 (7 weeds/m^2) than year 1 (125 weeds/m^2) because a shallow cultivation was necessary to remove weeds that germinated after an early fall storm with 24 mm (0.9”) of rain in late October 2004. This cultivation created a stale seedbed (Boyd et al., 2006), however, this scenario is unusual prior to cover cropping and preferably cover crops are planted before the first significant fall rains.

Increasing the seeding rate of rye (Trial 1) and the legume/oat mixture (Trials 2 and 3) improved weed suppression (Figure 3, 4, 5). With the rye cover crop, increasing seeding rate significantly reduced weed biomass early and mid season on both years. Weed biomass in the rye trial was higher in year 2 than year 1 across all seeding rates, and in year 2 increasing seeding rate increased weed suppression even at the last harvest. In year 2 with rye, the maximum amount of weed biomass (January) was reduced by about 50% with each incremental increase in seeding rate (Figure 3). With the legume/oat cover crop in Hollister, the effect of increasing seeding rate was only significant in year 1 when weeds were more abundant, and was not apparent until the January and March harvests (Figure 4). In Salinas, increasing seeding rate of the legume/oat cover crop improved weed suppression both years from the first harvest (Figure 5). The delayed weed suppression by the higher seeding rates of the legume/oat mix in Hollister but not in Salinas is probably due to climatic differences that increased the early season growth rate of the weeds in Salinas. In trials 1-3, the reduction in weed biomass with increased seeding rate was due to faster ground cover by the cover crops (data not shown). As in previous studies in this region (Brennan and Smith, 2005), weed biomass under the cover crops generally declined near the end of the cover cropping period. Based on our ongoing and previous studies, it is reasonable to assume that more weed seed production occurred at the lower seeding rates where more weed biomass was produced.

Cover crop seeding rate effects on cover crop biomass (Trials 1-3)

In trials 1-3 and in all years, increasing seeding rate increased total cover crop biomass production during the first 2 harvests ($p \leq 0.05$) but had no effect on the amount of cover crop biomass at the end of the season (Figures 6, 7, 8). The dynamics of cover crop biomass production are more complex with a mixed cover such as the legume/oat mix in trials 2 and 3 than with a monoculture because of competition between the legume and oat components. In both Salinas and Hollister, the legume proportion of the total cover crop biomass was highest (i.e. 64-83%) early in the season and declined thereafter. Increasing seeding rate increased legume biomass early in the season up to harvest 2 at both sites ($p \leq 0.05$), but not at the end of the season. Furthermore, although legume biomass was not affected by rate after harvest 2 in Salinas, legume biomass continued to increase through the season. In Hollister, legume biomass at the 1x rate did not change after harvest 2 in year 1, but increased slightly from harvest 2 to 4 in year 2. Whereas at the 2x and 3x rates in Hollister, legume biomass declined after harvest 2 in year 1, but was relatively stable at these rates after harvest 2 in year 2. Rate did not affect legume biomass at the final harvest at either site in either year. Across rates at both sites, legume biomass production at the end of the season varied less between years and sites than oat biomass production. For example, between year 1 and 2, oat biomass increased by 140% while legume biomass was only increased by 27% in Hollister. Similarly, in Salinas, legume biomass was 30% greater in year 1 than year 2, while oat biomass was 76% greater in year 1. Across rates and years at the end of the cover crop, legume biomass was higher in Salinas (3.9 Mg/ha, 1.7 t/a) than Hollister (1.6 Mg/ha 0.7 t/a), but oat biomass was higher in Hollister (7.3 Mg/ha, 3.3 t/a) than Salinas (4.3 Mg/ha, 1.9 t/a). These differences in the amount of legume versus oat biomass are probably due to soil fertility differences between the sites and are discussed below.

Cover crop mix composition effects on weeds (Trials 4-5)

The monoculture cover crops and mixed cover crops differed markedly in their ability to suppress weeds during the cover cropping period at both sites and years (Figure 9, 10). Of the moncultures, the legumes were far less weed suppressive then the non-legumes. Legume monocultures are seldom used as winter cover crops in this region, but their inability to suppress weeds even at relatively high seeding rates helps to explain why some legume-dominant mixes are so weedy. As monocultures, mustard and rye were generally better than oats at suppressing weeds; this agrees with our previous studies (Brennan and Smith, 2005; Brennan, unpublished data). However, weed suppression by mustard was less in year 2 than 1, because it was damaged by frost during an unusually cold period at the end of 2004. This experience and our other ongoing studies indicate that mustard's performance across years is more variable than that of other nonlegume cover crops (i.e. cereals). 'Lana' vetch was consistently the most weed-suppressive monoculture legume, indicating that it is probably the best vetch for inclusion in winter cover crop mixes. Unfortunately, the supply of 'Lana' vetch is generally lower and more variable between years than with other vetches (personal communication, Tom Hearne, L.A. Hearne Company).

In the first year, weed biomass in the mixes was in order of legume/oat > legume/rye > legume/mustard at both sites, but this pattern did not occur in the second year. It is unclear why mix 6 (10% rye, 90% legume) performed poorly in terms of weed suppression in year 2 in both Salinas and Hollister. As expected, increasing the percentage of oat or rye in a mixture from 10% (mix 1, 3, 6) to 40% (mix 2, 4, 7) increased weed suppression early in the season. In terms of weed suppression, the mixes with mustard were extremely variable at both sites and years. Weed suppression by the monoculture cover crops and mixes was generally related to their percent ground cover (data not shown), and to their cover crop biomass production in January and February (Figures 11 and 12).

It can be useful to evaluate weed growth in cover crops at several dates as in trials 1-3. In trials 4 and 5 we only sampled once due to the large number of cover crops evaluated. However, we are confident that the single sampling date provides a good overall measure of weed suppression because sampling occurred in late January and early February when weed biomass in cover crops typically peaks.

Cover crop mix composition effects on cover crop biomass (Trials 4-5)

Cover crop biomass production by the monocultures and mixes in trials 4 and 5 varied considerably between years, sites and harvest dates (Figures 11, 12, 13, 14). Averaged across all cover crops, biomass production at harvest 1 as a percentage of the final biomass at harvest 2 was 29% (year 1) and 57% (year 2) in Hollister, and 36% (year 1) and 56% (year 2) in Salinas. The higher biomass production earlier in year 2 at both sites was probably due to the warmer fall and winter in year 2 than year 1. Averaged across all cover crops, the final biomass was slightly higher in Hollister (8.5 Mg/ha, 3.8 t/a) than Salinas (8.3 Mg/ha, 3.7 t/a) in year 1, and also higher in Hollister (7.2 Mg/ha, 3.2 t/a) than Salinas (5.2 Mg/ha, 2.3 t/a) in year 2. The higher production values in Hollister are probably due to higher soil fertility in the clay soil in Hollister versus the loamy sand soil in Salinas. Differences in soil quality between the two sites may also help to explain why the total legume biomass production averaged across all cover crops was higher in Salinas than in Hollister, and also why legume biomass typically declined from harvest 1 to 2 in Hollister, but increased during this period in Salinas. Legumes are generally more competitive with non-legumes in lower fertility situations. It is interesting to note that the highest legume biomass production in Hollister occurred in the bell bean monoculture both years and in Salinas in year 1, whereas the legume biomass in several of the mixes was similar to that of monoculture bell beans in year 2 in Salinas.

In many cases, increasing the proportion of non-legumes (oat, rye, mustard) in a mix with legumes increased the non-legume biomass and reduced the legume biomass. This pattern was especially clear at harvest 1 when comparing the mixes with 10% oat and rye (i.e. mixes # 1, 4, 6, 9) with mixes with 40% oat or rye (i.e. mixes 2, 5, 7, 10). This trend also occurred in harvest 1 of year 2 at both sites as the percentage of mustard increased in mixes 13, 14 and 15. The ability of mustard to suppress the legumes even at low mustard seeding rates (i.e. 1.8 kg/ha, 2 lb/a in mix 13) indicates that mustards and legumes are not compatible components in a mix when a goal is to maximize growth and nitrogen fixation by the legume component.

Interpreting the dynamics of cover crop biomass production is complicated when the biomass of one component declines during the season as was especially obvious with the legumes in several mixes in Hollister. In such cases, the end-of-season biomass of the legume and non-legume components underestimate the total biomass production during the season. A more accurate measure of the total season production would be to add the maximum legume biomass that occurred during the season with the maximum biomass that occurred by the non-legume component. For example, with mix 4 (10% oat, 90% vetch) in year 2 in Hollister, the maximum legume biomass (3.1 Mg/ha, 1.4 t/a) occurred at harvest 1, whereas the maximum oat biomass (8.0 Mg/ha, 3.6 t/a) occurred at harvest 2. Thus the total biomass production by the cover crop during the season was their sum (11.1 Mg/ha, 5.0 t/a), which is much higher than the final harvest biomass (8.5 Mg/ha, 3.8 t/a). It is likely that the nutrients from senesced tissues (leaves, shoots and roots) are cycled back into the growth of surviving and dominant components when senescence occurs early in the season, and when conditions (moisture, temperature) and organisms (i.e. detritivores) promote decomposition. More research is needed to estimate the N balances and probable transfer from the legume to the cereal during the cropping season to improve survival of the legume component and improve the efficiency of legume-cereal intercropping systems (Ofori and Stern, 1987). In subsequent studies, we are measuring the biomass production of each legume species in mixes to better understand the changing role of each over the season.

6. CONCLUSIONS

Planting in a grid versus one-way pattern did not affect growth of the legume/oat mix, but did improve cover crop growth and weed suppression with rye in one year. However, increasing the rye seeding rate in the one-way planting pattern is probably a more cost effective and beneficial way to improve weed suppression than grid planting at a lower rate. Increasing the seeding rate of rye and the legume/oat mix up to three times the typical rate increased weed suppression and early season cover crop biomass production, but did not affect the final cover crop biomass production. The benefits of higher seeding rates are most likely to occur where weed densities are high, and over several years may help to reduce the weed seed bank. Increasing the seeding rate of mixed cover crop is complex because competition increases with seeding rate which in turn affects the survival and biomass production of the components in the mix. The trials with the various combinations of legumes, cereals and mustard showed large differences in weed suppression and cover crop biomass production of the various components in the mixes. It is important to emphasize that the performance of the various mixes in trials 4 and 5 is related to the composition of the mix and the seeding rate used. More research is needed to better understand the complex competition dynamics in cover crop mixes to develop mixes that scavenge nitrogen, suppress weeds, but also allow adequate growth and nitrogen fixation by the legume component. It is unclear if the potential benefits of the N fixation by the legume can be achieved in a mix that is planted at a high enough density to provide ample weed suppression.

The results of these trials provide information that will help farmers make decisions on seeding rate, planting arrangement and mixture composition to optimize the benefits of cover cropping and minimize weeds.

7. OUTREACH

A field day was held in collaboration between the Community Alliance with Family Farmers (Sam Earnshaw), the University of California Cooperative Extension, and the USDA-ARS in February 2004 that focused on the mixes in trials 4 and 5. Additional collaborative field days in February 2005 and 2006 focused on cover crop seeding rate effects. These field days occurred at the organic research land at the USDA-ARS in Salinas and were attended by organic and conventional farmers, educators, researchers, and others in the farming community. A preliminary summary of trial 1 and 2 was given in the Organic Research Matters newsletter (September, 2004). Three manuscripts that describe the studies in more detail are being prepared for submission to peer-reviewed journals. We plan to publish a summary of each trial in future issues of the Organic Research Matters newsletter.

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9. ADDENDA. Tables, pages 12-13; Figures, pages 14-27; Photographs, pages 28-29.

Table 1. Summary of Cover Crop Seeding Rate and Planting Arrangement Trials.

Trial	**Farm**	**Cover Crop**	**Seeding Rate** kg/ha (lb/acre)	**Planting Arrangement**	**Plant and biomass Harvest Dates**	
					2003-2004	**2004-2005**
1	Tanimura & Antle Salinas, CA	Rye[1]	1x: 90 (80) 2x: 179 (160) 3x: 269 (240)	one-way & grid	Plant: Oct 23, 03 H1: Dec 1, 03 H2: Jan 5, 04 H3: Feb 17, 04	Plant: Oct 18, 04 H1: Nov 29, 04 H2: Jan 6, 05 H3: Mar 1, 05
2	Phil Foster Ranch Hollister, CA	Leg/Oat Mix[2]	1x: 112 (100) 2x: 224 (200) 3x: 336 (300)	one-way & grid	Plant: Nov 3, 03 H1: Dec15-16, 03 H2: Jan 20, 04 H3: Mar 5, 04 H4: Apr 5, 04	Plant: Nov 8, 04 H1: Dec 13, 04 H2: Jan 27, 05 H3: Mar 14, 05 H4: Apr 22, 05
3	USDA-ARS Salinas, CA	Leg/Oat Mix	1x: 112 (100) 2x: 224 (200) 3x: 336 (300)	one-way	Plant: Nov 4, 03 H1: Dec 23, 03 H2: Feb 5, 04 H3: Mar 8-9, 04 H4: Apr 6, 04	Plant: Nov 9, 04 H1: Jan 12, 05 H2: Feb 17, 05 H3: Mar 17, 05 H4: Apr 26, 05

[1]Cereal rye (*Secale cereale*) 'Merced'. The standard seeding rate (1x) is 80 lb/a (90 kg/ha).
[2]Mix includes 10% 'Cayuse' oat (*Avena sativa*), 35% bell bean (*Vicia faba*), 25% 'Magnus' pea (*Pisum sativum*),15% common vetch (*Vicia sativa*) and 15% purple vetch (*Vicia benghalensis*) by seed weight. The standard seeding rate (1x) is 100 lb/a (112 kg/ha).

Table 2. Summary of cover crops used in trials 4 and 5.

		-------% Seed by Weight-------								
	Cover Crop Descriptions	**Oat[1]**	**Rye[2]**	**Mus[3]**	**Bell bean[4]**	**Pea[5]**	**C. vetch[6]**	**L. vetch[7]**	**P. vetch[8]**	**Seeding Rate kg/ha (lb/a)**
	Monocultures									
	Oat[1]	100								112 (100)
	Rye[2]		100							90 (80)
	Mustard[3]			100						11 (10)
	Bell bean[4]				100					140 (125)
	Pea[5]					100				112 (100)
	Common vetch[6]						100			67 (60)
	Lana vetch[7]							100		67 (60)
	Purple vetch[8]								100	67 (60)
Mix #	**Leg/Oat Mixes**									
1 *	10% Oat 90% Leg	10			35	25	15		15	140 (125)
2 *	40% Oat 60% Leg	40			23	17	10		10	140 (125)
3 [A]	10% Oat 90% Leg +lv	10			23	17	10	30	10	140 (125)
4	10% Oat 90% vetch	10						45	45	140 (125)
5	40% Oat 60% vetch	40						30	30	140 (125)
	Leg/Rye Mixes									
6	10% Rye 90% Leg		10		35	25	15		15	140 (125)
7	40% Rye 60% Leg		40		23	17	10		10	140 (125)
8 [B]	10% Rye 90% Leg+lv		10		23	17	10	30	10	140 (125)
9	10% Rye 90% vetch		10					45	45	140 (125)
10	40% Rye 60% vetch		40					30	30	140 (125)
	Leg/Cereal/Mus Mixes									
11 [C]	10% Oat 90% Leg+mus	9.8		1.6	34.5	24.6	14.8		14.8	142 (127)
12 [D]	10% Rye 90% Leg+mus		9.8	1.6	34.5	24.6	14.8		14.8	142 (127)
	Leg/Mus Mixes									
13 [E]	Leg+2lb/a mus			1.7	38.2	27.3	16.4		16.4	142 (114.5)
14 [E]	Leg+4lb/a mus			3.4	37.6	26.8	16.1		16.1	142 (116.5)
15 [E]	Leg+6lb/a mus			6.6	36.3	26	15.6		15.6	142 (120.5)
16	Bell bean mustard			5				95		140 (125)
17	Vetch mustard			4		48	48			140 (125)

[1]10% 'Cayuse' oats (*Avena sativa*). [2]Cereal rye (*Secale cereale*) 'Merced'. [3] Mustard is mix of 69% 'Ida Gold' (*Sinapsis alba*) and 31% 'Pacific Gold' (*Brassica juncea*) by seed weight. [4]*Vicia faba*. [5]'Magnus' pea (*Pisum sativum*), [6]Common vetch, *Vicia sativa.* [7]Purple vetch, *Vicia benghalensis*. [8] 'Lana' vetch, *Vicia villosa ssp. Dasycarpa* .

[A] Similar to mix 1, but also includes 'Lana' vetch and has fewer peas and bell beans.

[B] Similar to mix 3, but also includes 'Lana' vetch and has fewer peas and bell beans.

[C] Similar to mix 1, but also included 2lb/a of mustard.

[D] Similar to mix 3, but also included 2lb/a of mustard.

[E] Mixes 13, 14, and 15 are similar to mix 1, without oats, plus 2, 4, and 8lb/a mustard. The legumes are seeded at the same rate as mix 1.

* Mixes 1 and 2 are relatively common, widely planted, commercially available mixes in California.

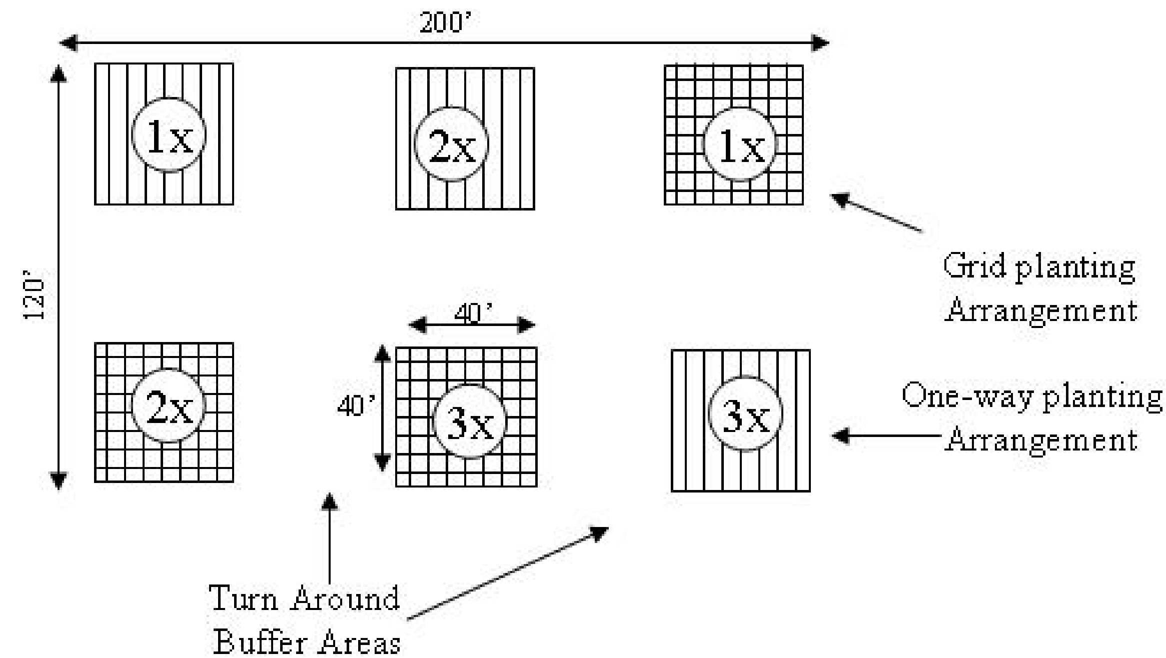


Figure 1. Randomized layout of the 6 treatments (3 seeding rates x 2 planting arrangements) in 1 of 4 replicates in **trials 1 and 2**. The number in each box (plot) indicates seeding rate that is described in table 1. Cover crops were to be planted in the turn-around buffer areas after the treatment plots were planted.

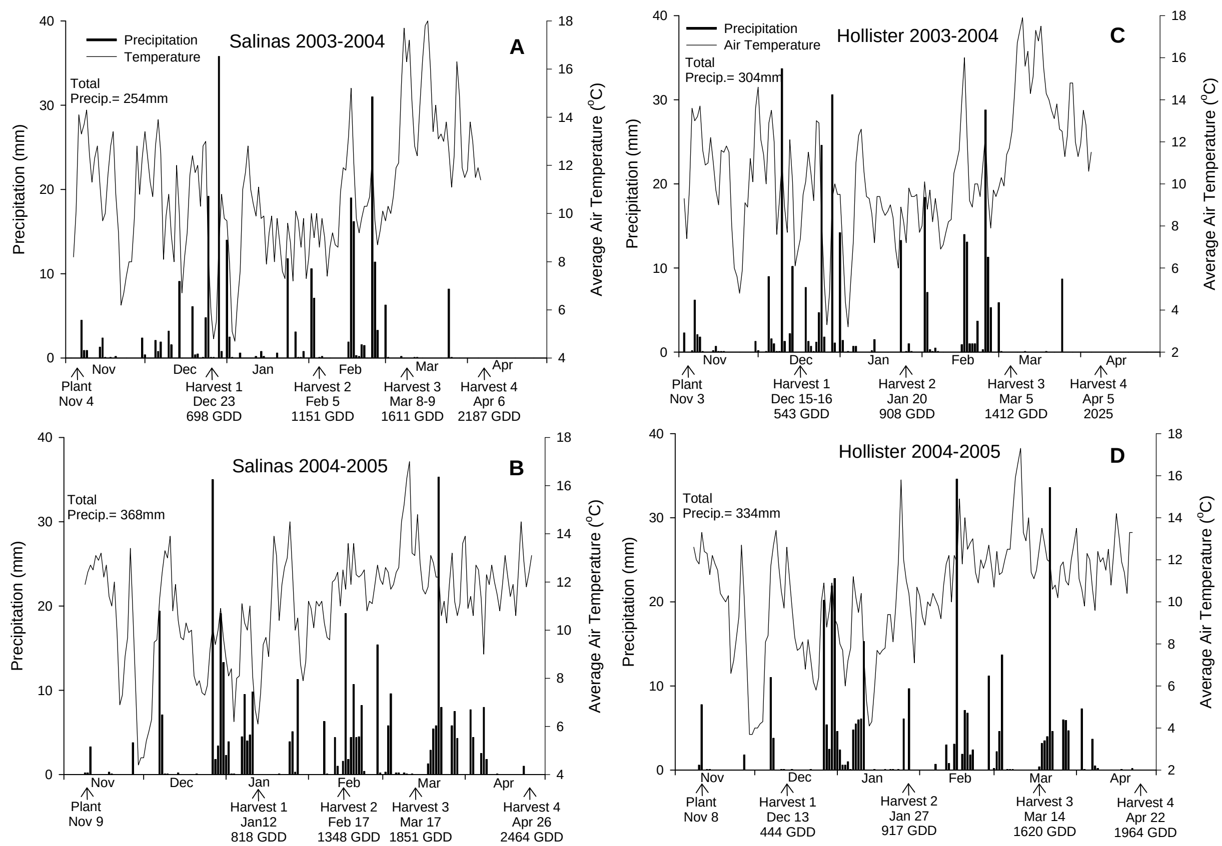


Figure 2. Daily mean air temperature and precipitation from the California Irrigation Management Information System at Salinas (A, B, station #89) and Hollister (C, D, station #126) available at http://wwwcimis.water.ca.gov. Biomass harvest dates and growing degree day accumulation (GDD) are indicated for each site and year. GDD are calculated with the single sine method with a baseline threshold of 4^{o} C using the online calculator at the University of California Statewide Integrated Pest Management web site at http://www.ipm.ucdavis.edu. 1 inch=25.4 mm.

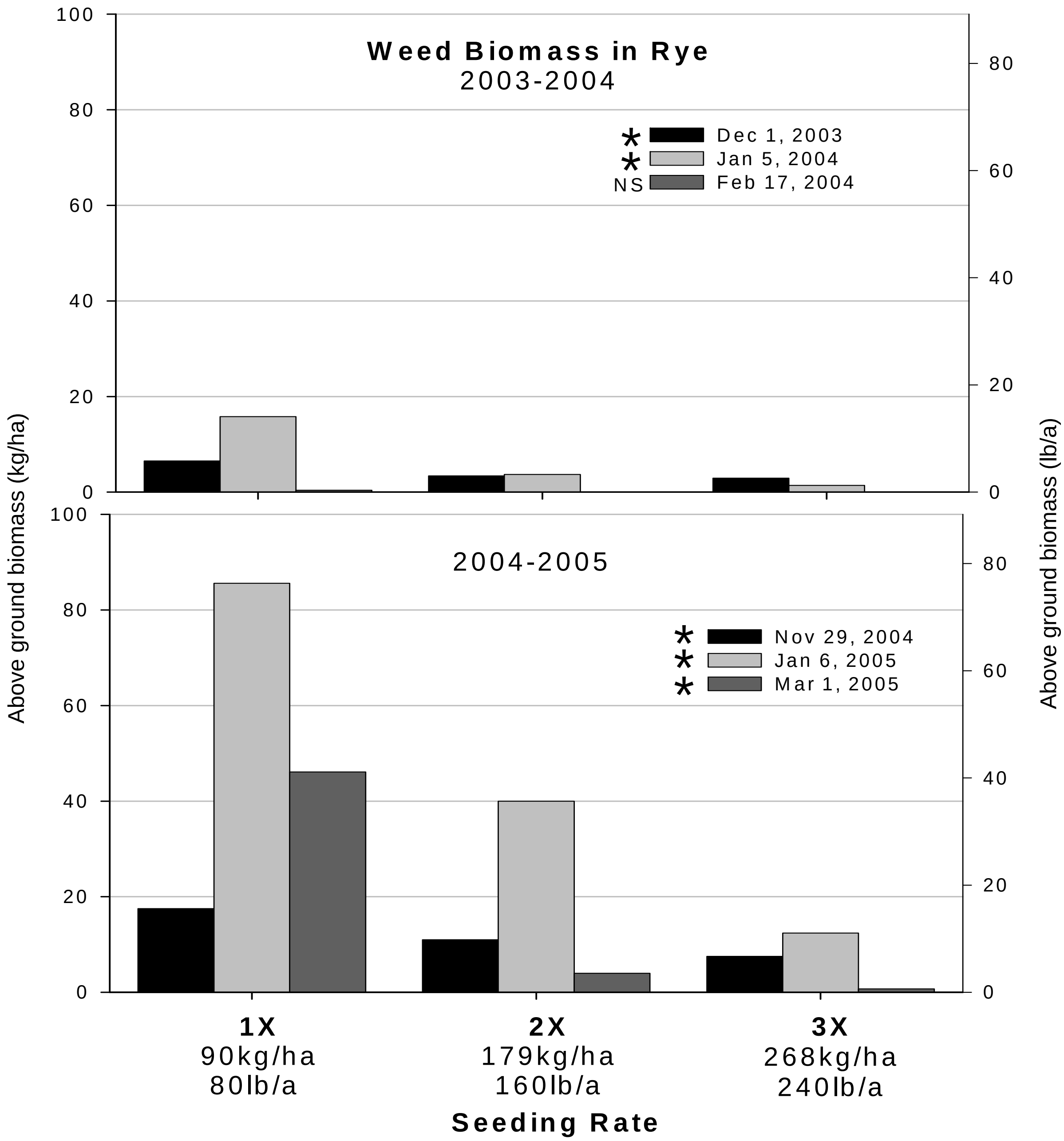


Figure 3. Weed biomass production at three harvest dates in a rye cover crop planted at three seeding rates during two years in Salinas (Trial 1). Bars are means averaged across the grid and one-way planting patterns. Within each harvest date and year, an * before the date legend indicates that increasing seeding rate significantly reduced weed biomass at the $P \leq 0.05$ level, whereas NS indicates that rate did not affect weed biomass.

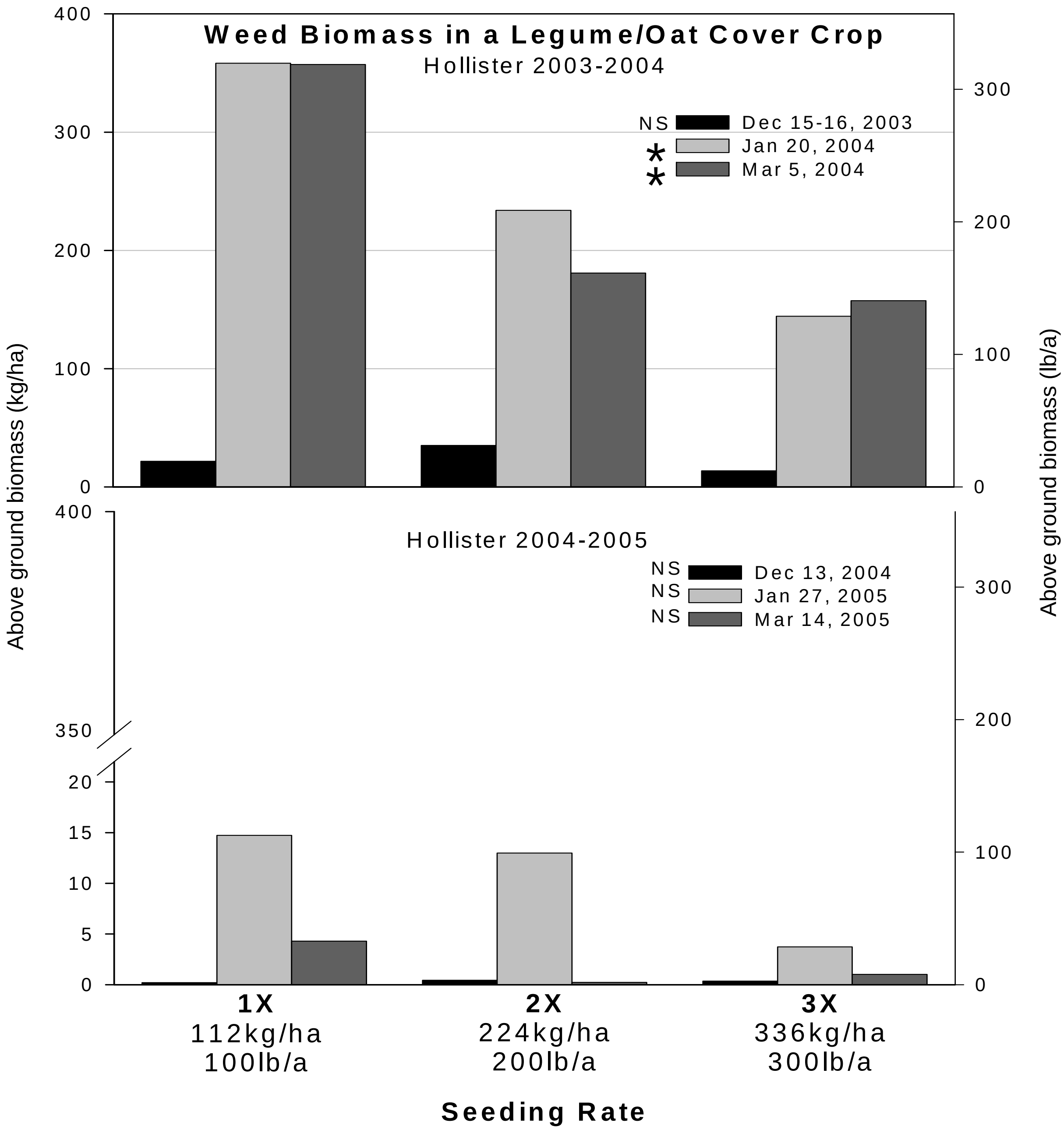


Figure 4. Weed biomass production at three harvest dates in legume/oat crop planted at three seeding rates during two years in Hollister (Trial 2). Bars are means across grid and one-way planting arrangement. Within each harvest date and year, an * before the date legend indicates that increasing seeding rate significantly reduced weed biomass at the P≤0.05 level, whereas NS indicates that rate did not affect weed biomass.

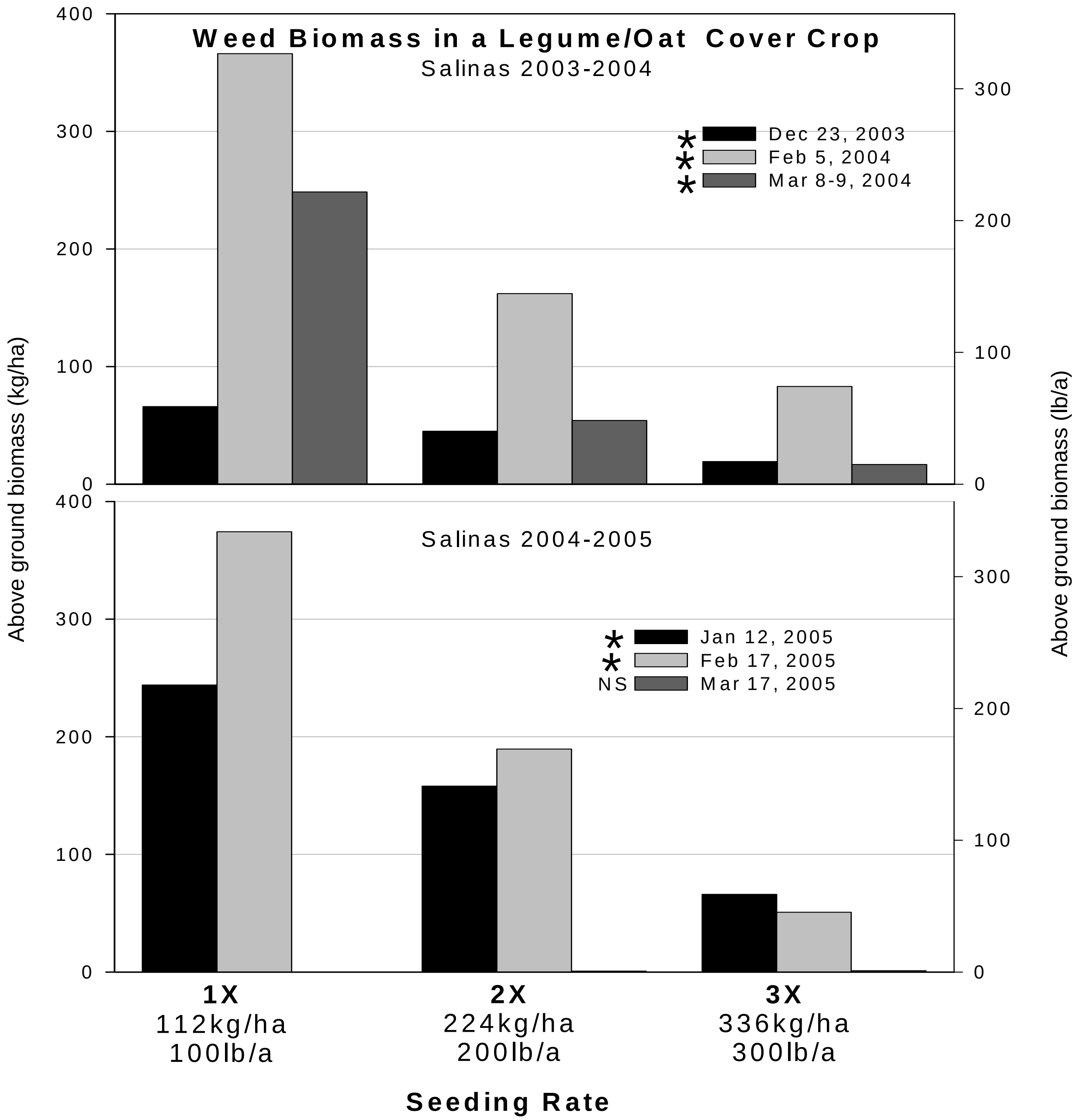


Figure 5. Weed biomass production at three harvest dates in legume/oat crop planted at three seeding rates during two years in Salinas (Trial 3). Bars are means. Within each harvest date and year, an * before the date legend indicates that increasing seeding rate significantly reduced weed biomass at the P≤0.05 level, whereas NS indicates that rate did not affect weed biomass.

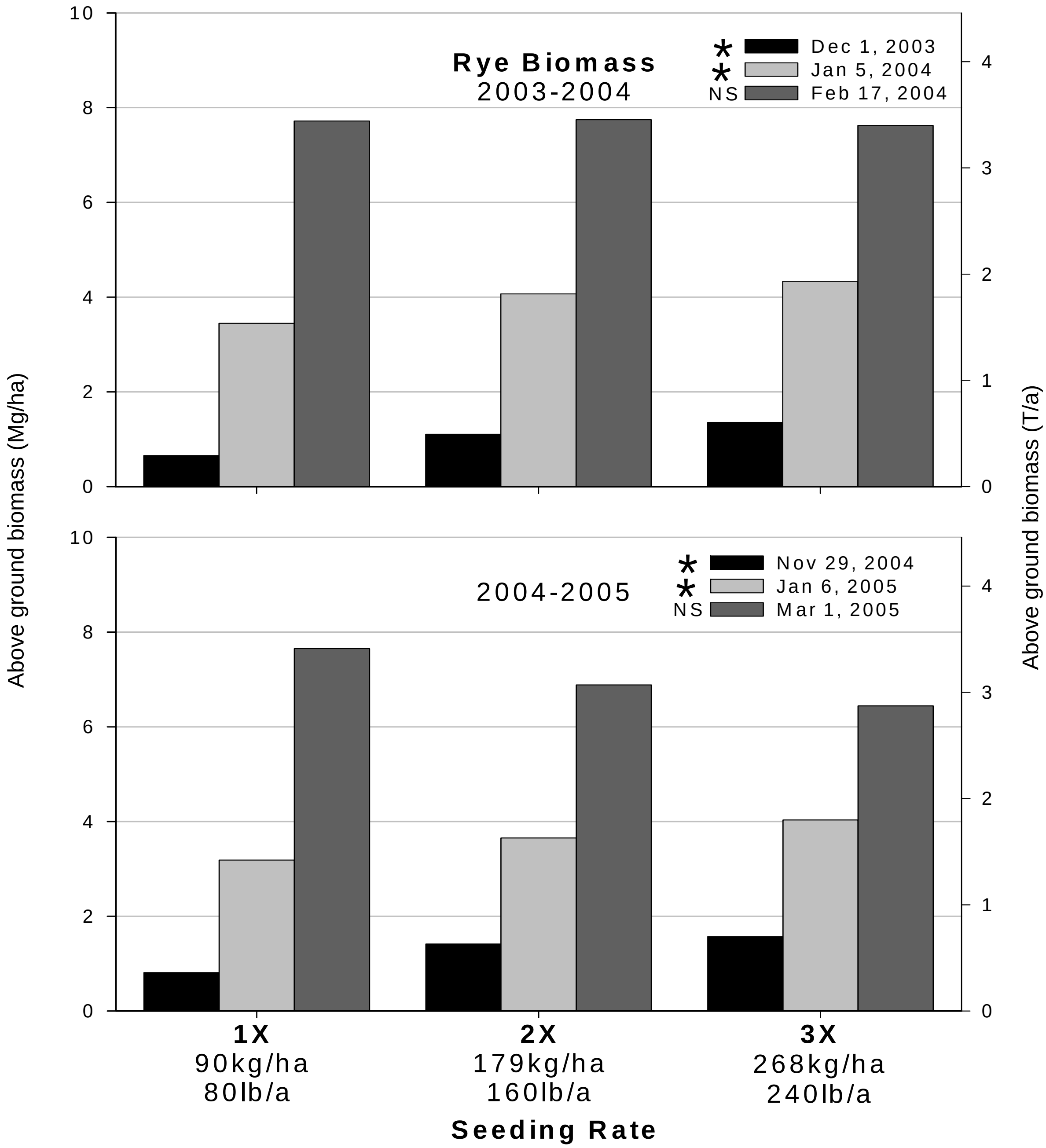


Figure 6. Rye biomass production at three harvest dates during two years in Salinas (Trial 1). Bars are means averaged across the grid and one-way planting patterns. Within each harvest date and year, an * before the date legend indicates that increasing seeding rate significantly reduced weed biomass at the P≤0.05 level, whereas NS indicates that rate did not affect weed biomass.

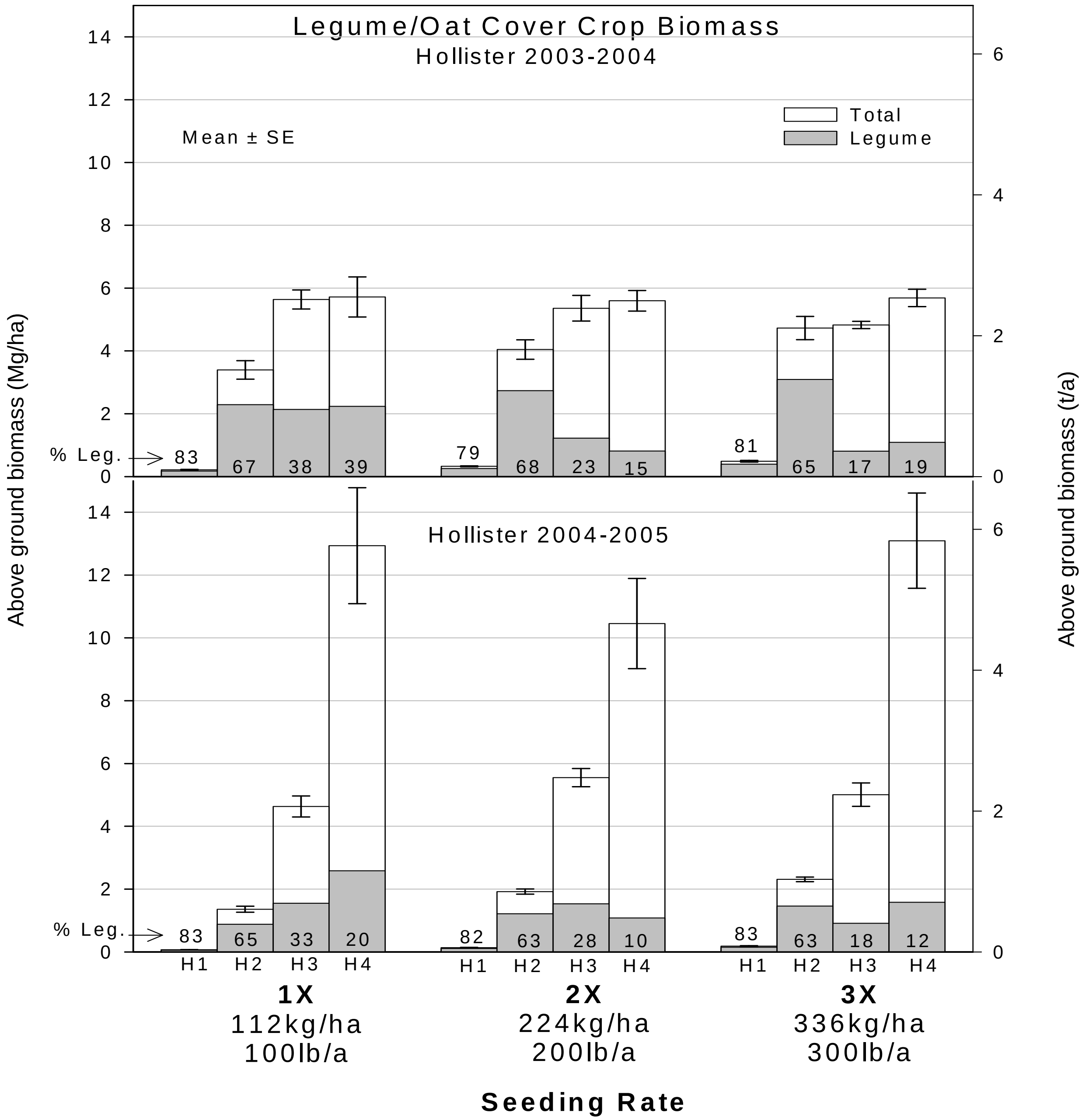


Figure 7. Legume/oat biomass production at four harvest dates (H1 to H4) during two years in Hollister (Trial 2). Bars are means averaged across the grid and one-way planting patterns. The grey region of each bar is the legume biomass, and the number in the bottom of each bar is the % legume biomass of total cover crop biomass. Within each year, increasing seeding rate significantly increased total cover crop biomass production at harvest 1 and 2.

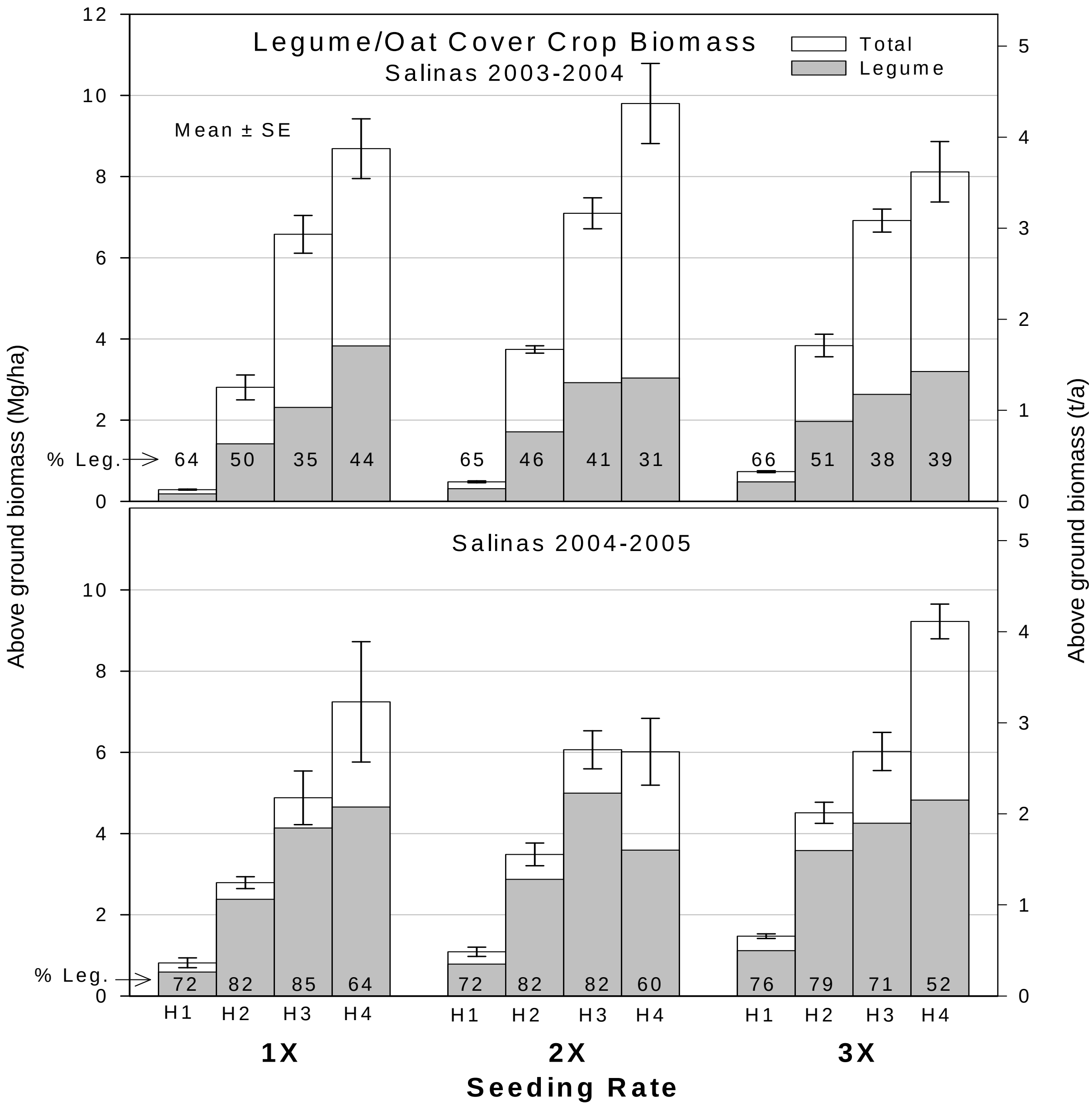


Figure 8. Legume/oat biomass production at four harvest dates (H1 to H4) during two years in Salinas (Trial 3). Bars are means averaged across the grid and one-way planting patterns. The grey region of each bar is the legume biomass, and the number in the bottom of each bar is the % legume biomass of total cover crop biomass. Within each year, increasing seeding rate significantly increased total cover crop biomass production at harvest 1 and 2.

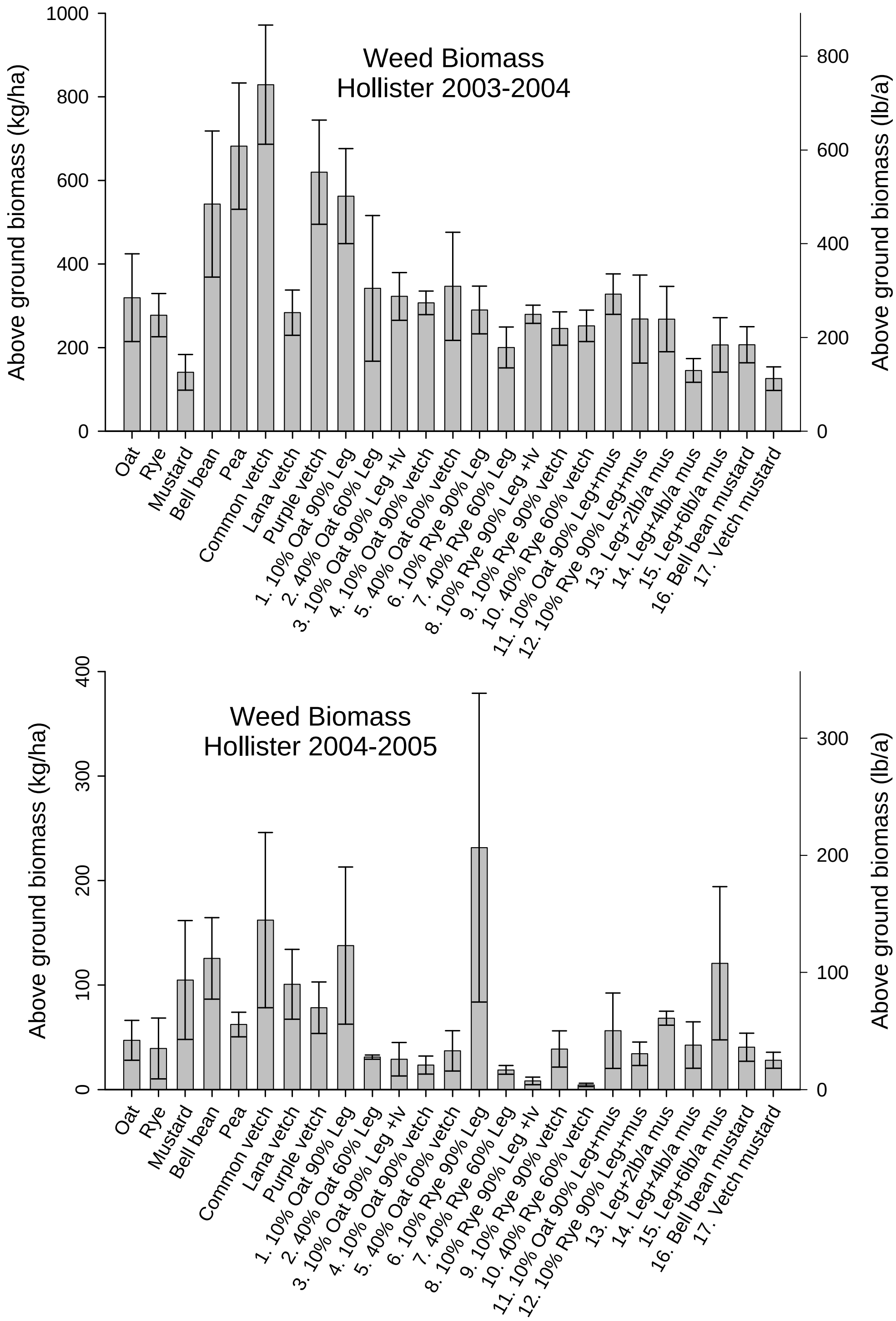
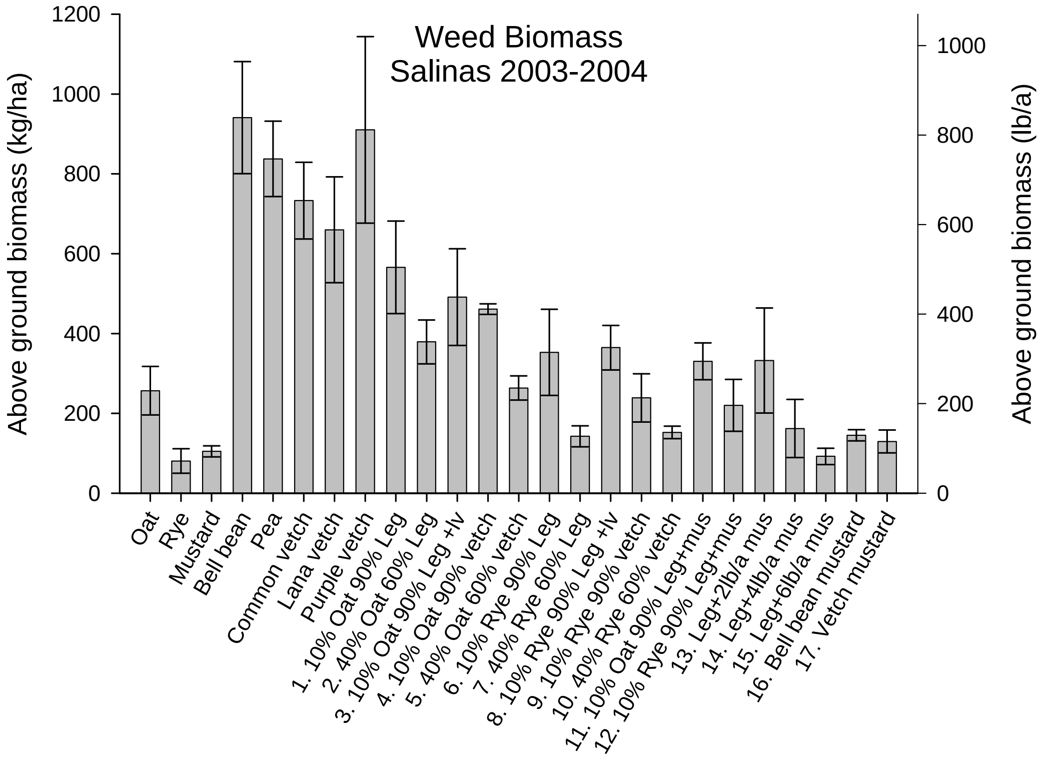


Figure 9. Weed biomass production under 8 pure and 17 mixed cover crops in Hollister (Trial 4) at January 28-29 in year 1, and January 31 to February 1 in year 2. Bars are mean±standard error. The harvest dates were January 28-29 in year 1, and January 31-February 1 in year 2. Note that the range of the y-axes differ between years.



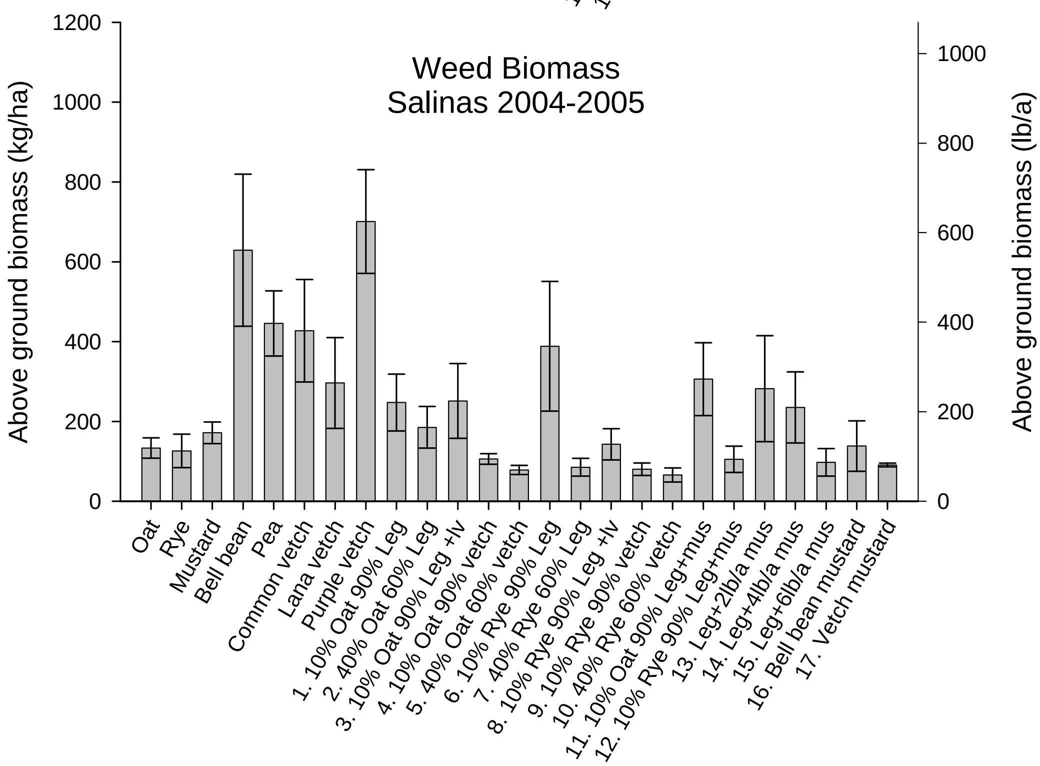
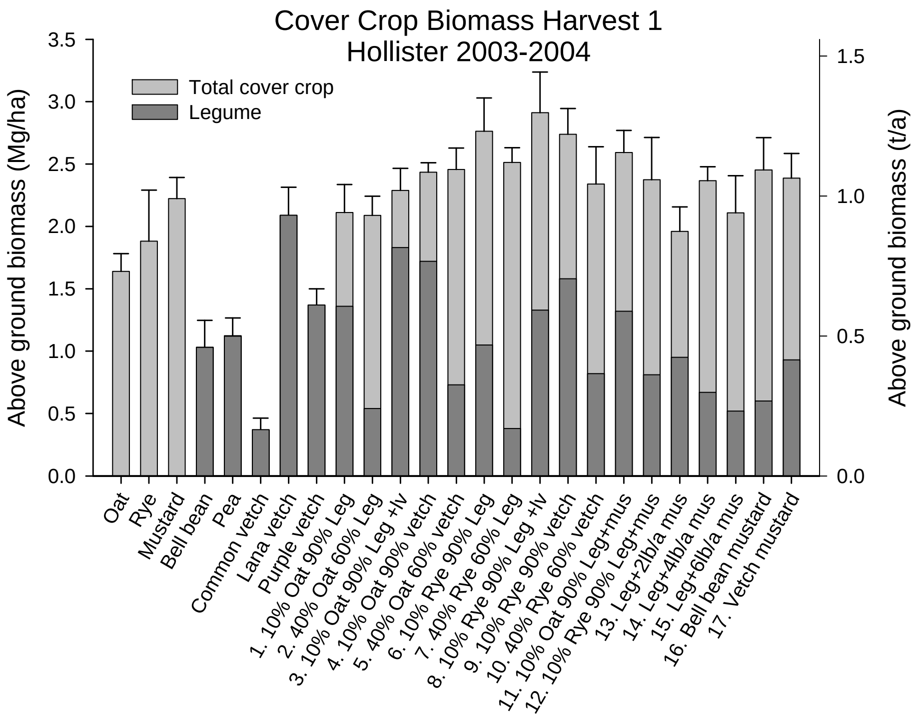


Figure 10. Weed biomass production under 8 pure and 17 mixed cover crops in Salinas (Trial 5) during two years. Bars are mean±standard error. The harvest dates were January 26-30 in year 1, and February 2-3 in year 2.



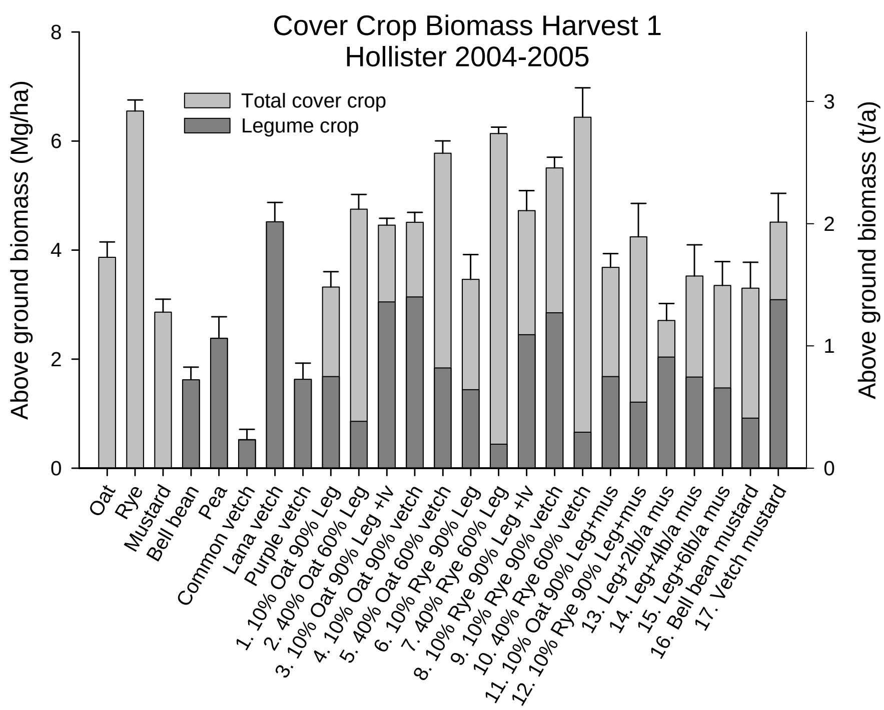


Figure 11. Cover crop biomass production of 8 pure and 17 mixed cover crops in Hollister (Trial 4) at January 28-29 in year 1, and January 31 to February 1 in year 2. The dark grey region of each bar is the legume biomass. Bars are mean+standard error . Note that the range of the y-axes differ between years.

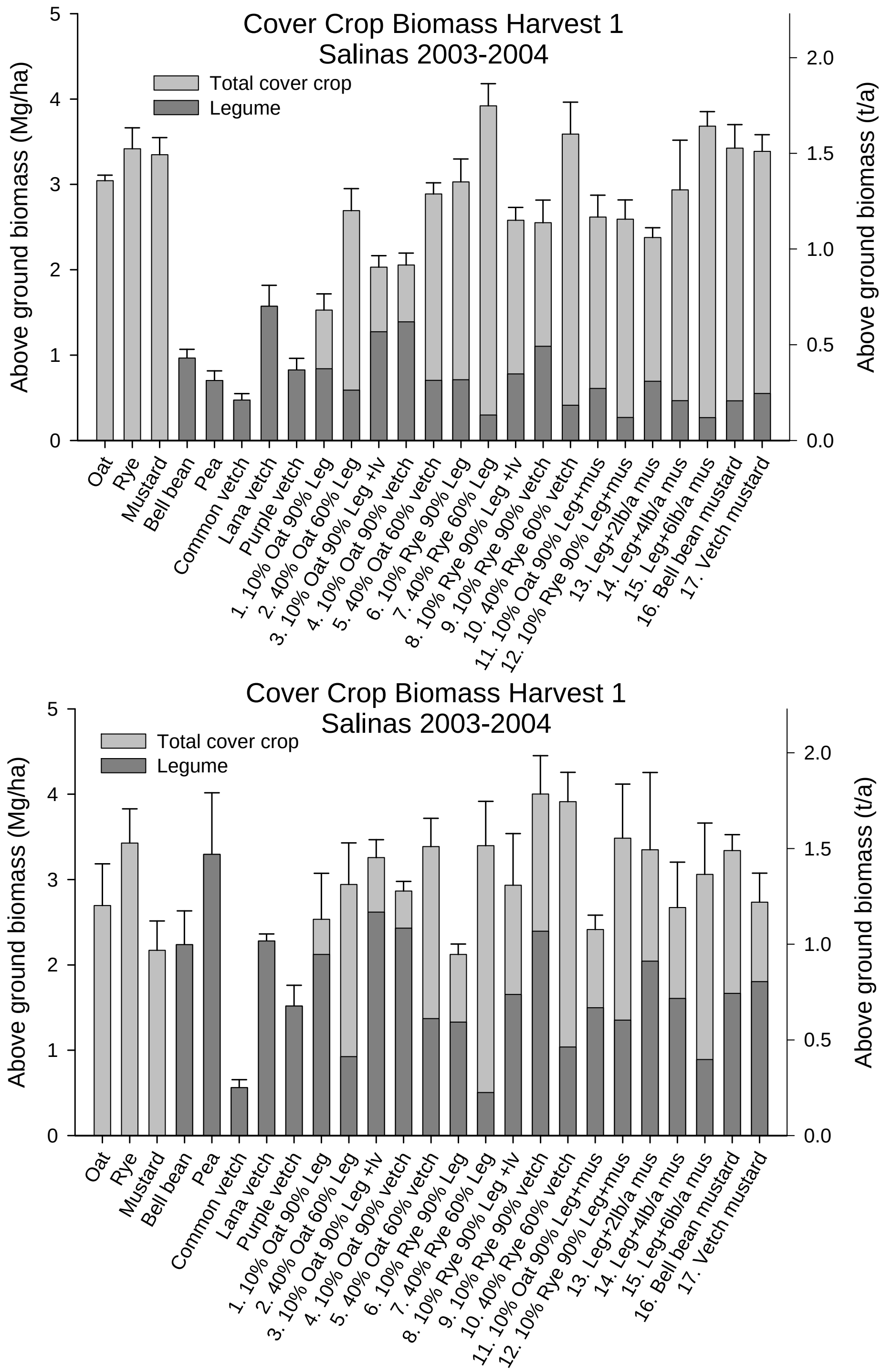
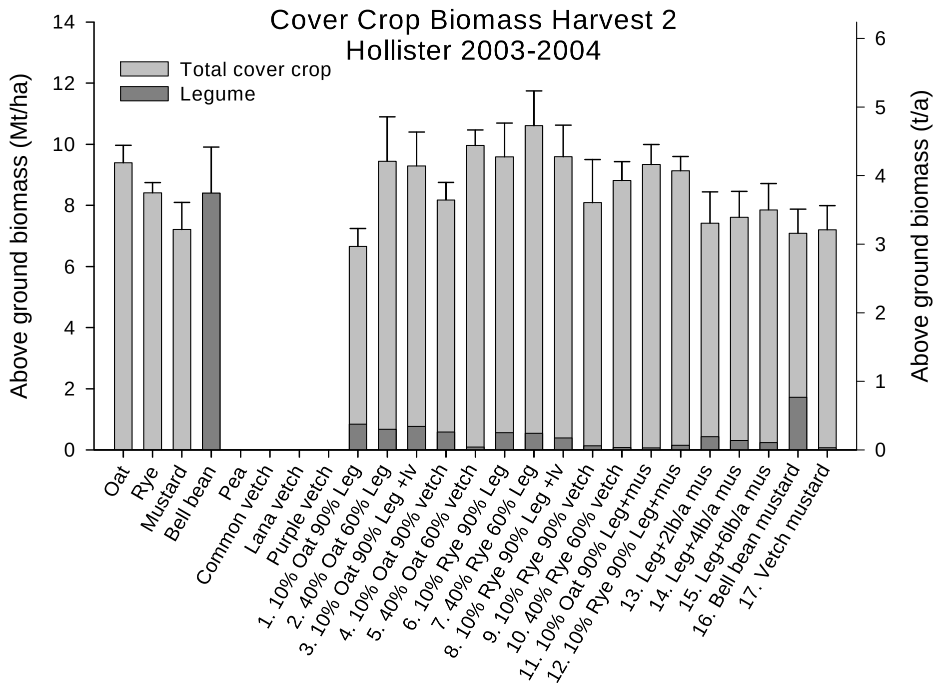


Figure 12. Cover crop biomass production of 8 pure and 17 mixed cover crops in Salinas (Trial 5) at January 26-30 in year 1, and February 2-3 in year 2. The dark grey region of each bar is the legume biomass. Bars are mean+standard error .



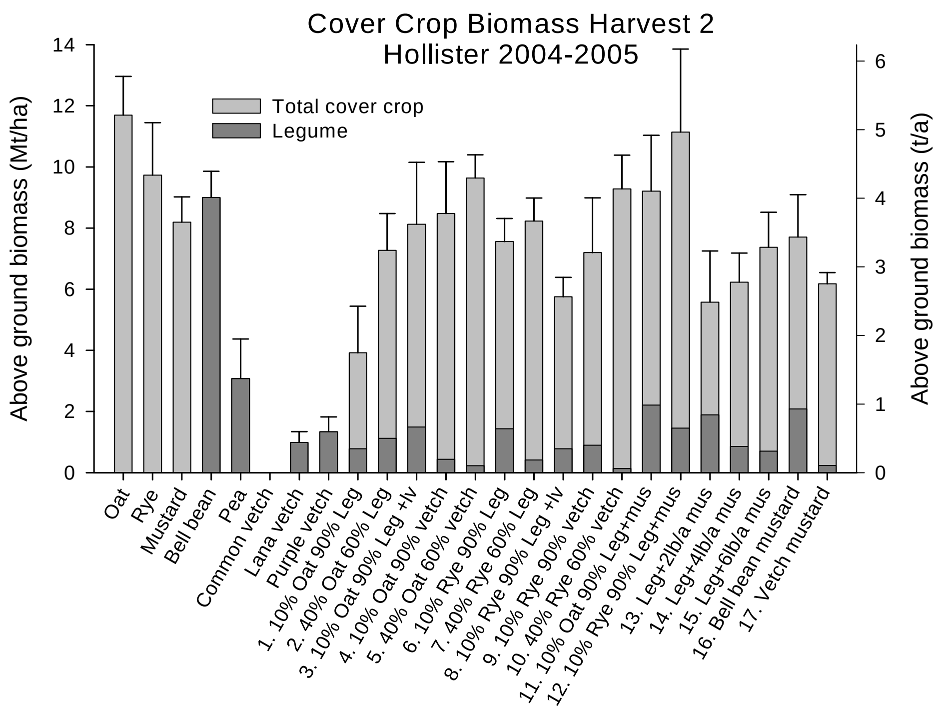
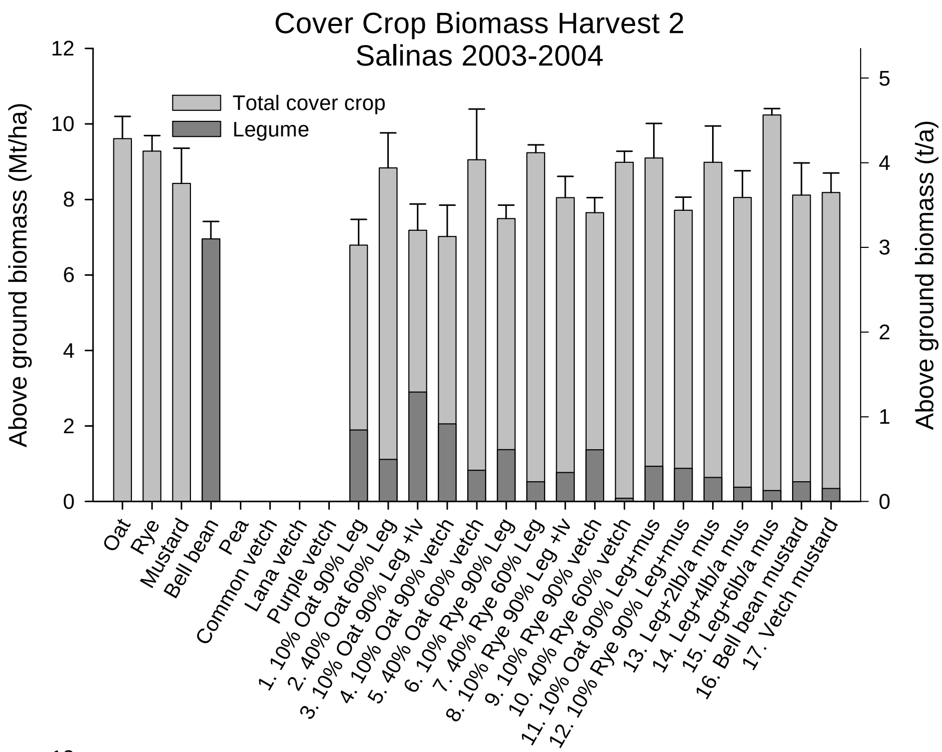


Figure 13. Cover crop biomass production of 8 pure and 17 mixed cover crops in Hollister (Trial 4) at March 29 in year 1, and April 7-11 in year 2. The dark grey region of each bar is the legume biomass. Bars are mean+standard error. Biomass was not harvested from common vetch either year, or from pea, lana vetch or purple vetch in year 1.



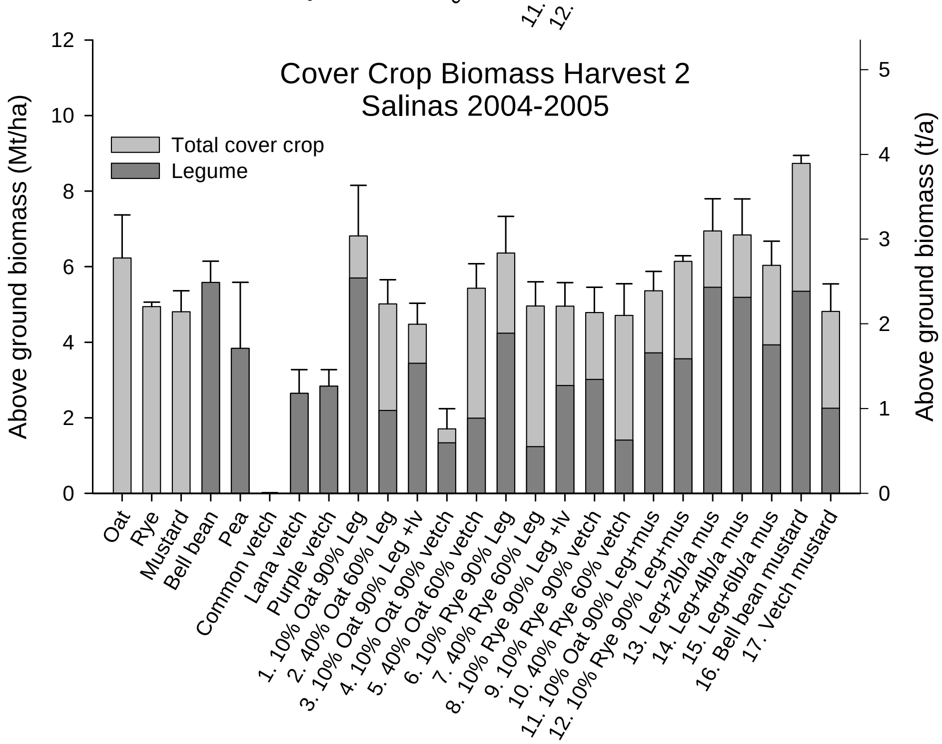


Figure 14. Cover crop biomass production of 8 pure and 17 mixed cover crops in Salinas (Trial 5) at March 23-24 in year 1, and March 30-31 in year 2. The dark grey region of each bar is the legume biomass. Bars are mean+standard error. Biomass was not harvested from common vetch either year, or from pea, 'Lana' vetch or purple vetch in year 1.


Photograph 1: Planting cover crop trials in Hollister.

Photograph 2. Seed cones on research grain drill for precision planting.


Photograph 3. Legume/oat cover crop trial 2 in Hollister, December 16, 2003.


Photograph 4. Cover crops mix trial 4 in Hollister, March 29, 2004

Photograph 5. Ladybird beetles on a legume/rye cover crop in Hollister, March 29, 2004.

Photograph 6. Cover crop field day focused on mixes, February, 2004.

Photograph 7. 'Merced' rye cover crop planted in one-way pattern at 80lb/a at the Tanimura & Antle farm in Salinas, November 24, 2003.

Photograph 8. 'Merced' rye cover crop planted in grid pattern at 80lb/a at the Tanimura & Antle farm in Salinas, November 24, 2003.

Photograph 9. 'Merced' rye cover crop planted in one-way pattern at 240lb/a at the Tanimura & Antle farm in Salinas, November 24, 2003.

Photograph 10. 'Merced' rye cover crop planted in grid pattern at 240lb/a at the Tanimura & Antle farm in Salinas, November 24, 2003.

Photograph 11. Seed sample from mix 1 with 10% 'Cayuse' oats, 35% bell bean, 25% 'Magnus' pea, 15% purple vetch, and 15% common vetch.

Photograph 12. Seed sample from mix 2 with 40% 'Cayuse' oats, 23% bell bean, 17% 'Magnus' pea, 10% purple vetch, and 10% common vetch.