Effect of Seeding Rate and Planting Arrangement on Rye Cover Crop and Weed Growth

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ABSTRACT

Weed growth in winter cover crops in warm climates may contribute to weed management costs in subsequent crops. A 2-yr experiment was conducted on an organic vegetable farm in Salinas, California, to determine the impact of seeding rate and planting arrangement on rye (*Secale cereale* L. 'Merced') cover crop growth and weed suppression. Each year, rye was planted in October at three rates (90, 180, and 270 kg ha^{-1}) and two planting arrangements (one-way versus grid pattern). Averaged across years, rye population densities were 322, 572, and 857 plants m^{-2} at the 90, 180, and 270 kg ha^{-1} seeding rates, respectively. Early season rye ground cover increased with seeding rate and was higher in the grid than one-way arrangement in Year 1; however, rye ground cover was not affected by rate and was higher in the one-way arrangement in Year 2. Aboveground dry matter (DM) of rye increased with seeding rate at the first two harvests but not at the final one. Planting arrangement did not affect rye aboveground DM in Year 1, but rye DM was higher in the grid pattern at the first and final harvests in Year 2. Weed emergence was not affected by seeding rate or planting arrangement. Weed biomass decreased with increased seeding rate and was also lower in the grid than in the one-way arrangement in Year 2. A grid planting pattern provided no consistent benefit but planting rye at higher seeding rates maximizes early season rye DM production and minimizes weed growth.

Cover crops are important in sustainable production systems and are commonly planted on organic vegetable farms on the central coast of California. Cover crops can improve cash crop yields, soil quality, pest and disease management, nutrient cycling, and N-use efficiency (Dabney et al., 2001; Hartwig and Ammon, 2002; Tonitto et al., 2006). Most published cover crop research from the central coast of California has focused on nitrate leaching and nitrogen cycling by nonleguminous cover crops including rye (Jackson et al., 1993; Wyland et al., 1996; Jackson, 2000). Rye is a popular winter cover crop in this region because it grows well, is a good nitrogen scavenger, and seldom produces viable seed before it is terminated in the spring.

Research in Salinas, CA, found that weed seed production during winter cover cropping can be substantial (Brennan and Smith, 2005; Boyd and Brennan, 2006) and may increase weed problems in subsequent vegetable crops. Minimizing weed seed production during all phases of a rotation is especially important in relatively warm climates where many weed species occur year round, and in organic systems where weed management is particularly expensive (i.e., >$1200 ha^{-1} crop^{-1}).

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Published in Agron. J. 101:47–51 (2009).
doi:10.2134/agronj2008.0059

Increasing crop density improves crop competitive ability and hastens competition for limited resources (Puckridge and Donald, 1967), and thus can reduce weed biomass and weed seed production (Teasdale, 1998; Mohler, 2000, p. 269–321.). Crop competitive ability can also be increased by improving planting uniformity. Olsen et al. (2005a; 2005b) found that wheat produced more biomass and had less weed biomass as wheat density and planting uniformity increased. Planting in a grid pattern with two perpendicular passes at half the normal seeding rate is a simple way to increase planting uniformity. A grid planting arrangement may increase the rate at which the ground is covered, and reduce intracrop competition. Increased crop density combined with a more uniform planting distribution should enable crops to compete more successfully with weeds (Weiner et al., 2001).

Recommended seeding rates for rye cover crops range from 67 to 336 kg ha^{-1} (Grant et al., 1983; Miller et al., 1989; Sustainable Agriculture Network, 1998; Ingels et al., 1998). The typical seeding rate for winter rye planted in a solid stand in the central coast region of California is 90 kg ha^{-1}. There are no previous studies on optimal seeding rates for winter rye cover crops for this region.

The objective of our study was to investigate the effects of seeding rate and planting arrangement on the growth, development, and weed suppressive ability of a rye cover crop.

MATERIALS AND METHODS

The study occurred during two winter periods from 2003 to 2005 on a certified organic vegetable farm in Salinas, CA. A different area of the same field was used each year. The soil type is a Salinas clay loam (fine, montmorillinitic, thermic chromic Pelloxererts). The average rainfall during the typical winter cover cropping period (October 15–March 1) from

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

Table 1. Cover crop planting and data collection dates, cumulative growing degree days, and cumulative precipitation for Year 1 and Year 2.

Activity	Year 1			Year 2		
	Date	GDD†	Precip.‡	Date	GDD	Precip.
		°C	mm		°C	mm
Cover crop planting	23 Oct. 2003	19	0	18 Oct. 2004	14	0.1
Rye plant counts	10 Nov. 2003	286	24	4 Nov. 2004	230	50
Ground cover 1	10 Nov. 2003	286	24	10 Nov. 2004	309	51
Ground cover 2	20 Nov. 2003	413	26	22 Nov. 2004	462	62
Weed and tiller counts	24 Nov. 2003	445	26	23 Nov. 2004	471	62
Harvest 1	1 Dec. 2003	524	31	29 Nov. 2004	532	64
Harvest 2	5 Jan. 2004	894	174	6 Jan. 2005	933	210
Harvest 3	17 Feb. 2004	1350	224	1 Mar. 2005	1576	326

† GDD (growing degree days) are calculated with the single sine/horizontal method with a baseline threshold of 0°C using the online calculator at the University of California Statewide Integrated Pest Management website at www.ipm.ucdavis.edu. Temperature and rainfall data were from station no. 116 (Salinas, North) of the California Irrigation Management Information Systems available at www.cimis.water.ca.gov.

‡ Cumulative precipitation.

1995 to 2005 was 308 mm (Table 1). Year 1 was drier (264 mm) and Year 2 was wetter (344 mm) than the 10-yr average. Approximately twice as much rain occurred between planting and Harvest 1 in Year 2 as in Year 1. The earlier planting and later termination dates in Year 2 resulted in 226 more growing degree days accumulated in Year 2 than Year 1.

Before the trial, baby greens (mustard [*Sinapis alba* L.] and lettuce [*Lactuca sativa* L.]) and celery [*Apium graveolens* L. var. *dulce* (Mill.) Pers.] were grown in 2003 and 2004, respectively. Field preparation included deep ripping and discing as necessary. The 'Merced' rye cover crop was planted in October each year (Table 1) with a 4.6-m-wide grain drill (Model 1500, Great Plains Mfg., Salina, KS) with 15-cm row spacing. The drill has double disc openers that precede rubber press wheels. The grain drill was modified with four seed cones (Kinkaid Equipment Mfg, Haven, KS) for precise control of seeding rate in small plots. Three seeding rates (90, 180, and 270 kg ha^{-1}) and two planting arrangements (one-way versus grid pattern) were evaluated. Seeding rates will be referred to as 1× , 2× and 3× , for the 90, 180, and 270 kg ha^{-1}, respectively. The grid arrangement was achieved by planting in two perpendicular passes with half of the one-way seeding rate in each direction. The 1000 kernel weights and percent germination of the rye seed were 21 g (98%) and 16.5 g (94%) in Year 1 and 2, respectively. Sprinkler irrigation was used as needed to stimulate germination before the onset of winter rainfall. In this paper, Year 1 refers to the cover crop period from October 2003 to February 2004, and Year 2 refers to the cover cropping period from October 2004 to March 2005 (Table 1).

The measurement and biomass harvest dates are listed in Table 1. Rye and weed population densities were determined by counting the number of plants in two 50- by 50-cm quadrats 18 days after planting (DAP) in November each year. Rye ground cover was measured by holding a 30- by 30-cm quadrat with 64 cross grids approximately 50 cm above the ground and counting the number of grid crosses that were over rye vegetation on 18 and 28 DAP in Year 1, and 23 and 35 DAP in Year 2. These values were converted to percent ground cover. The number of tillers per plant in 5 randomly chosen plants per plot, and the height of 10 randomly chosen plants per plot was determined 32 DAP in Year 1 and 36 DAP in Year 2. Aboveground cover crop and weed DM was determined by harvesting a 100- by 50-cm quadrat in each plot at three times through each cover cropping period. All of the harvested material was sorted into weeds and rye plant material at harvest. For DM determination, samples were ovendried at 65°C for at least 48 h until their weights had stabilized. Rye was at the inflorescence emergence to anthesis stage at the final DM harvests and was then terminated by flail mowing and discing.

The experiment was a randomized complete block design with four blocks and six treatments (three seeding rates by two planting arrangements). 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 with rye at 90 kg ha^{-1}. The data were subjected to ANOVA with the MIXED procedure in SAS version 9.1 (SAS Inst., Cary, NC). The rye plant counts and weed aboveground DM were log (x+1) transformed to ensure the assumptions of equal variance and normality were met, and back-transformed least squares means are presented. T-type confidence limits (0.95) were constructed for the least square means with the CL option following the LSMEANS statement in SAS. Analyses of DM were stratified by year and harvest due to differences in the harvest intervals each year, and significant year by harvest effects. Analyses of population density, ground cover were also stratified by year due to differences between years. Single df, orthogonal, polynomial contrasts (linear and quadratic) were used to determine the response of the dependant variables to seeding rate. The contrast coefficients were 1, 0, –1, and 1, –2, 1, for the linear and quadratic contrasts, respectively. In all analyses, significance was determined at the $P \leq 0.05$ level.

RESULTS AND DISCUSSION

Plant Counts

Rye population density increased linearly with seeding rate both years and also quadratically in Year 1. Sixty-two percent of the planted seeds emerged across rates, planting arrangements, and years (Table 2). Rye seedling mortality was 34% assuming an average of 96% germination across years. The cause of the high rye seedling mortality was not determined but could be due to disease, insects, or abiotic factors. We attribute the higher plant density at all seeding rates in Year 2 to the smaller seed (16.5 g 1000 $kernels^{-1}$) than in Year 1 (21 g 1000 $kernels^{-1}$) and increased levels of precipitation in Year 2 (Table 1). We used the same seeding rates (kg ha^{-1}) in our trial regardless of 1000 kernel weight because this is the typical practice of farmers in this area. Brennan and Smith (2005) highlighted the importance of reporting information on stand density in cover crop trials rather than just reporting seeding rate in weight per area. Selecting the seeding rate to achieve a target plant density based on seed size, percent germination, and expected seedling mortality could improve the cover crop performance and reduce seed costs.

Rye densities at the 2× and 3× seeding rates were slightly less than 2 and 3 times the 1× rate. Seedlings were more difficult to distinguish at higher densities, which may account for the difference or the difference may indicate that a larger proportion of plants emerged at the 1× seeding rate as in studies with wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and rye (Juskiw et al., 2000; Whaley et al., 2000; Zhao et al., 2007). Planting arrangement did not affect rye density either year, which suggests

Table 2. Seeding and population densities of rye and rye ground cover at two dates.

Treatments	Seeding density	Population density	Ground cover 1	Ground cover 2
	seeds m^{-2}	plants m^{-2}	%	
2003–2004				
Seeding rate, kg ha^{-1}				
90 (1×)	429	272	16	52
180 (2×)	858	526	26	73
270 (3×)	1287	721	36	83
Planting arrangement				
Grid†		473	27	74
One-way†		466	25	65
Significance				
Rate		***	***	***
Linear‡		***	***	***
Quadratic‡		***	ns	*
Arrangement		ns§	ns	**
Rate × arrangement		ns	ns	ns
2004–2005				
Seeding rate, kg ha^{-1}				
90 (1×)	545	371	31	88
180 (2×)	1090	617	36	88
270 (3×)	1635	993	35	87
Planting arrangement				
Grid		598	30	83
One-way		624	38	91
Significance				
Rate		***	ns	ns
Linear		***	ns	ns
Quadratic		ns	ns	ns
Arrangement		ns	ns	*
Rate × arrangement		ns	ns	ns

* Significant at the $P < 0.05$ level within year.

** Significant at the $P < 0.01$ level within year.

*** Significant at the $P < 0.001$ level within year.

† Averaged across seeding rates.

‡ Single df, orthogonal, polynomial contrasts of seeding rate.

§ ns = not significant at the $P < 0.05$ level within year.

Table 3. Rye plant height and tillering averaged across years and planting arrangements.

Treatments	Height	Tillers
	mm	tillers plant^{-1}
Seeding rate, kg ha^{-1}		
90 (1×)	138 (130, 147)†	2.3 (2.0, 2.6)
180 (2×)	181 (172, 189)	2.0 (1.7, 2.2)
270 (3×)	221 (212, 229)	1.7 (1.4, 2.0)
Planting arrangement		
Grid‡	178 (171, 186)	2.0 (1.8, 2.3)
One-way‡	182 (174, 189)	2.0 (1.8, 2.2)
Significance		
Rate	***	**
Linear§	***	***
Quadratic§	ns¶	ns
Arrangement	ns	ns
Rate × arrangement	ns	ns

** Significant at the $P < 0.01$ level.

*** Significant at the $P < 0.001$ level.

† Numbers in parentheses are the 95% confidence limits for the least squares means.

‡ Averaged across seeding rates.

§ Single df, orthogonal, polynomial contrasts of seeding rate.

¶ ns = not significant at the $P < 0.05$ level.

that the emergence of the rye seed sown in the first pass through the field was unaffected by the second pass. Cover crops with smaller seeds (i.e., mustard) may not tolerate the potential increased compaction and soil disturbance from two passes over the same area as well as rye.

Rye Canopy Development

Ground cover increased linearly with seeding rate at both sampling dates in Year 1 but did not increase with seeding rate in Year 2 (Table 2). Ground cover in Year 2 may have been unaffected by rate because the rye densities were higher than in Year 1. Ground cover was higher in the grid than in the one-way arrangement only at the second sampling date in Year 1. In contrast, ground cover was significantly higher in the one-way arrangement at the second sampling date in Year 2. We initially expected that ground cover would be consistently higher in the grid arrangement because of the increased planting uniformity. Olsen and Weiner (2007) found that the leaf area index of spring wheat increased with seeding rate and was higher in a spatially uniform arrangement than in a row arrangement. Grant et al. (1983) reported that the leaf area index increased with seeding rate in rye cover crops. The percent ground cover by rye at the higher seeding rates (2× , 3×) in Year 1 and at all rates in Year 2 at 28 to 35 DAP were similar to that of winter mustard cover crops that were good weed suppressors (Brennan and Smith, 2005).

Rye Tillering and Height

Plants exhibit phenotypic plasticity by adjusting their form to adapt to various stresses (Read and Stokes, 2006). This was apparent in our study where increasing seeding rate increased linearly rye height and reduced linearly the number of tillers early in the season (32 and 36 DAP in Year 1 and 2, respectively) (Table 3). Tillering is influenced by light and is typically reduced by increasing seeding rate and competition (Stoskopf, 1985; Peltonen-Sainio et al., 2002; Venuto et al., 2004). Although we did not measure rye height at the termination of the experiment, there were no apparent differences between treatments similar to the ones observed in late November. Peltonen-Sainio et al. (2002) reported that increasing the seeding rate from 300 to 700 seed m^{-2} reduced rye height from 136 to 132 cm, but in some years increased lodging from 34 to 70%. Lodging is undesirable in cereals for grain production, but is acceptable in cover crops that are flail mowed before incorporation into the soil. Increased lodging in tall wheat cultivars was negatively correlated with annual weed densities (Wicks et al., 2004).

Aboveground Rye DM Production

Aboveground DM of rye increased linearly with seeding rate at Harvest 1 and 2, and was especially apparent at Harvest 1 when the 1× rate had approximately half the DM as the 3× rate (Table 4). Grant et al. (1983) similarly found that aboveground and belowground DM of rye increased with seeding rate from 21 to 35 DAP. Aboveground rye DM at the end of the season was unaffected by seeding rate in both years. The lack of difference can be attributed at least in part to the compensatory growth through increased tillering. Similarly, wheat aboveground DM production at harvest was unaffected by plant density (Whaley et al., 2000). Planting arrangement did not affect rye DM production in Year 1; however, rye DM was higher in the grid than in the one-way arrangement at Harvest 1 and 3 in Year 2. It is unclear why this affect varied between years and was not consistent across rates in Year 2. With spring and winter wheat, Olsen et al. (2005a; 2005b) reported higher wheat DM in a grid than in a row planting arrangement, and also at higher seeding rates.

Table 4. Aboveground DM of the rye cover crop at three harvests.

Treatment	Harvest 1	Harvest 2	Harvest 3
		$Mg\ ha^{-1}$	
2003–2004			
Seeding rate, $kg\ ha^{-1}$			
90 (1×)	0.7 (0.5, 0.8)†	3.4 (3.2, 3.7)	7.7 (6.4, 9.1)
180 (2×)	1.1 (1.0, 1.2)	4.1 (3.8, 4.4)	7.7 (6.4, 9.1)
270 (3×)	1.4 (1.2, 1.5)	4.3 (4.0, 4.6)	7.6 (6.3, 9.0)
Planting arrangement			
Grid‡	1.0 (0.9, 1.2)	4.0 (3.7, 4.2)	7.6 (6.6, 8.7)
One-way‡	1.0 (0.9, 1.2)	3.9 (3.7, 4.2)	7.7 (6.7, 8.8)
Significance			
Rate	***	**	ns
Linear§	***	***	ns
Quadratic§	ns¶	ns	ns
Arrangement	ns	ns	ns
Rate × arrangement	ns	ns	ns
2004–2005			
Seeding rate			
90 (1×)	0.8 (0.6, 1.0)	3.2 (2.8, 3.6)	7.7 (6.3, 9.0)
180 (2×)	1.4 (1.3, 1.6)	3.7 (3.2, 4.1)	6.9 (5.6, 8.2)
270 (3×)	1.6 (1.4, 1.7)	4.0 (3.6, 4.5)	6.4 (5.1, 7.8)
Planting arrangement			
Grid	1.4 (1.3, 1.5)	3.7 (3.3, 4.0)	7.8 (6.7, 8.9)
One-way	1.1 (1.0, 1.3)	3.6 (3.2, 3.9)	6.2 (5.1, 7.3)
Significance			
Rate	***	*	ns
Linear	***	**	ns
Quadratic	*	ns	ns
Arrangement	*	ns	*
Rate × arrangement	ns	ns	ns

* Significant at the $P < 0.05$ level within year.

** Significant at the $P < 0.01$ level within year.

*** Significant at the $P < 0.001$ level within year.

† Numbers in parentheses are the 95% confidence limits for the least squares means.

‡ Averaged across seeding rates.

§ Single df, orthogonal, polynomial contrasts of seeding rate.

¶ ns = not significant at the $P < 0.05$ level within year.

Table 5. Mean aboveground DM of weeds in a rye cover crop at three harvest dates.

Treatments	Harvest 1	Harvest 2	Harvest 3
$kg\ ha^{-1}$		$kg\ ha^{-1}$	
2003–2004			
Seeding rate			
90 (1×)	5.7 (3.4, 9.0)†	12.0 (7.3, 19.2)	0.3 (0, 0.6)
180 (2×)	3.0 (1.6, 5.0)	3.5 (1.9, 6.0)	0.1 (-0.2, 0.3)
270 (3×)	2.7 (1.4, 4.5)	1.1 (0.4, 2.3)	0 (-0.2, 0.3)
Planting arrangement			
Grid‡	3.2 (1.9, 5.0)	4.1 (2.5, 6.4)	0.1 (-0.1, 0.4)
One-way‡	4.0 (2.5, 6.2)	3.9 (2.4, 6.1)	0.1 (-0.1, 0.3)
Significance			
Rate	*	***	ns
Linear§	*	***	ns
Quadratic§	ns¶	ns	ns
Arrangement	ns	ns	ns
Rate × arrangement	ns	ns	ns
2004–2005			
Seeding rate			
90 (1×)	15.0 (10.4, 21.6)	47.4 (20.3, 109.0)	11.5 (3.9, 30.3)
180 (2×)	9.6 (6.6, 14.0)	21.6 (8.9, 50.4)	1.0 (0, 3.3)
270 (3×)	7.1 (4.7. 10.4)	10.1 (3.9, 24.3)	0.3 (-0.4, 1.8)
Planting arrangement			
Grid	8.3 (6.0, 11.2)	20.4 (9.9, 40.8)	0.6 (-0.1, 2.0)
One-way	12.4 (9.1, 16.7)	23.8 (11.7, 47.4)	5.5 (2.2, 12.2)
Significance			
Rate	*	*	**
Linear	**	*	***
Quadratic	ns	ns	ns
Arrangement	ns	ns	**
Rate × arrangement	ns	ns	ns

* Significant at the $P < 0.05$ level within year.

** Significant at the $P < 0.01$ level within year.

*** Significant at the $P < 0.001$ level within year.

† Numbers in parentheses are the 95% confidence limits for the least squares means.

‡ Averaged across seeding rates.

§ Single df, orthogonal, polynomial contrasts of seeding rate.

¶ ns = not significant at the $P < 0.05$ level within year.

The final DM production for rye in our study averaged across treatments and years (7.3 $Mg\ ha^{-1}$) was considerably higher than previous reports from the central coast region of 3.6 to 4.4 $Mg\ ha^{-1}$ (Jackson et al., 1993; Wyland et al., 1996). Rye DM in these previous studies may have been lower than in our study because the rye was sown about a month later and at extremely low seeding rates (9 to 18 $kg\ ha^{-1}$) on beds rather than in a solid stand; most cover crops are planted in solid stands in this region. Nevertheless, this low seeding rate reduced nitrate leaching by 65 to 70% compared with winter fallow plots (Wyland et al., 1996). We hypothesize that maximizing stand density and rye cover crop biomass in the fall would increase nitrate uptake. Total N uptake has been shown to increase with seeding rate due to higher DM production (Arduini et al., 2006). Mays et al. (2003) also showed a correlation between DM and N uptake in wheat and rye at various fall planting dates. In wheat, crop nitrogen uptake increased with seeding rate up to the onset of stem extension, but did not differ by the time the flag leaf has fully emerged (Whaley et al., 2000). However, when comparing different types of cover crops, Kristensen and Thorup-Kristensen (2004) found that nitrate uptake was related more to rooting depth rather than to aboveground DM.

Weed Densities and Biomass

Weed densities were 38 and 26 plants m^{-2} in Year 1 and 2, respectively, and were dominated by shepherd's purse [*Capsella bursa-pastoris* (L.) Medic.] that comprised 70 and 48% of the total weeds, and burning nettle (*Urtica urens* L.) with 22 and 40% of the total weeds in Year 1 and 2, respectively. Weed densities in the present study were much lower than in previous cover crop studies in the region where densities ranged from 154 to 1474 plants m^{-2} (Brennan and Smith, 2005; Boyd and Brennan, 2006). Weed emergence was unaffected by seeding rate or planting arrangement (data not shown). The lack of a cover crop treatment effect on weed emergence in our study agrees with previous work in the area with a variety of other winter cover crops (Brennan and Smith, 2005). However, cover cropping practices can change the weed seed bank density (Moonen and Barberi, 2004) and consequently affect weed emergence over several years.

Weed biomass declined linearly with increasing seeding rate at the early and midseason harvests both years, and weed biomass was generally highest in January (Table 5). The number of weeds producing seeds was not determined but visual observations suggested that most weeds within the cover crop died before flowering. Despite the lower weed emergence in Year 2 than Year 1, weed biomass was several times higher in Year 2.

It is unclear why weed biomass was higher in Year 2, given the proportionally higher cover crop emergence and the high early-season ground cover and biomass production by the cover crop in Year 2 than in Year 1. We assume that the earlier planting date and higher rainfall during the first 30 DAP in Year 2 caused the higher weed biomass in Year 2 than Year 1. Weed biomass reported in other winter cover crop trials in the central coast region ranged from 50 to 1870 kg ha^{-1} (Brennan and Smith, 2005; Boyd and Brennan, 2006). Planting arrangement only affected weed biomass in Year 2 with significantly greater weed biomass in the one-way arrangement versus the grid pattern. The effect of arrangement did not differ significantly with seeding rate. In spring and winter wheat, Olsen et al. (2005a; 2005b) found that weed biomass declined with increasing rate and weed biomass was consistently lower in a grid than standard row planting arrangement. The high weed densities (i.e., 1000 m^{-1}) and high weed biomass (i.e., 1500 kg ha^{-1}) reported in these previous studies may explain why the grid pattern was more consistently more weed suppressive than in our study. Our study relied on natural weed populations, whereas these previous studies comparing planting arrangements sowed weeds to ensure high weed pressure.

CONCLUSION

Planting in a grid pattern required two passes through the field that would likely double dust production, fuel use, planting time, and labor needed to plant a cover crop. We do not believe that grid planting is worthwhile considering these disadvantages and the inconsistent and relatively small improvement in weed suppression and rye DM production with the grid pattern. However, planting rye at higher seeding rates would be beneficial because this consistently improved early- to midseason rye biomass production and weed suppression. Growth of annual weeds in a cover crop is only detrimental if the weeds produce seeds that increase weed management costs. Doubling the seeding rate from 90 to 180 kg ha^{-1} would double the seed cost for cover cropping but not the total cover cropping cost because seed typically accounts for less than 20% of cover cropping costs when planting, early-season irrigation, mowing, and discing costs are considered (Tourte et al., 2004). The increase in rye DM with increasing seeding rate up to 70 to 80 DAP suggests that the higher rates may be worthwhile to hasten DM production and thus, shorten the cover cropping period to achieve yields of 4 Mg ha^{-1}.

ACKNOWLEDGMENTS

This research was supported partially by a grant from the Organic Farming Research Foundation. The authors would like to thank the farming crew of Tanimura & Antle for their technical assistance. We also thank Bruce Mackey for assistance with statistical analysis and Susanne Klose and Richard Rosecrance for improving this manuscript.

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