ORGANIC FARMING RESEARCH FOUNDATION

Project report submitted to the Organic Farming Research Foundation:

Project Title:

Targeted Mowing to Increase Allelopathy of Rye Cover Crop in a Tomato Production System

FINAL PROJECT REPORT

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Project Summary

This project examined whether targeted mowing of winter rye cover crop (*Secale cereale* L.) would increase its weed suppression ability by increasing levels of rye's major allelochemicals, Hydroaxamic acids (Hx), and subsequently increase crop yield in an organic tomato production system. The project was conducted on organic farms in Upper Marlboro (2003), and Beltsville (2004), Maryland, using a rye cover crop that was grown as a monoculture and as a mixture with crimson clover, and black mulch. Mowing treatments consisted of unmowed rye and spring-mowed rye. The effect of mowing rye on tomato production was tested in the absence and presence of redroot pigweed (*Amaranthus retroflexus*) seeds scattered between tomato plants. Results of laboratory bioassays on pigweed seed germination showed that rye shoots were more allelopathic than roots. Bioassays of rye from rye-clover plots and unleached rye plots showed that mowing extended the duration of allelopathic activity of shoots more than unmowed rye, but only marginally increases the level of toxicity of rye shoots. There was no effect of mowing rye on levels of Hx, suggesting that the effect of mowing may be the results of unidentified allelochemicals. Field results showed that rye cover crops significantly suppressed pigweed germination in rye plots compared to pigweed germination in the plastic mulch control, but the effect of mowing on this suppression was not detected. Tomato production data in 2003 showed that tomato growth and yield in mowed rye was as high as those in the plastic mulch control, while growth and yield in unmowed rye was lower than those in the plastic mulch control. This mowing effect was only seen in rye grown as a monoculture. Tomato production in mowed rye-clover plots was significantly lower than those in plastic mulch, while production in unmowed rye-clover plots was as high as the plastic mulch. These results suggest that mowing rye cover crop can increase tomato production if the rye is grown as a monoculture in a resource-limited environment, but that the addition of a nitrogen producing cover crop can affect the response of rye to mowing. However, the increase in tomato yield is not likely the result of a reduction in redroot pigweed emergence given the low field germination rates seen with the experimentally planted redroot pigweed. The effect of mowing on yield may be due to a reduction in natural weed populations. Tomato production in 2004 was not affected by either cover crop or mowing, which is likely due to the higher level of soil fertility, and lower plant competition in the Beltsville farm. In conclusion, use of targeted mowing of winter rye appears to provide a competitive advantage to a cash crop when grown as a monoculture in a resource-limited environment. As such, mowing rye is recommended when growing it as a monoculture in such an environment, but without further investigating the effects of rye mowing in cover crop mixtures, mowing rye is not recommended when rye is grown in combination with legumes.

Introduction:

Winter rye (*Secale cereale* L.) has been used as a cover crop because of its ability to suppress weeds, and scavenge soil nutrients such as nitrogen. The weed suppression ability of rye has been mostly attributed to allelopathy, the process by which rye's allelochemicals inhibit weed germination and growth. This project is the second of a two-part project that aims to help farmers integrate organic practices in their vegetable production system. The two-part project addresses whether the suppression of weeds by rye can be enhanced with targeted mowing. Targeted mowing is an organic method to increase weed suppression with little added labor to the farmer. It involves mowing rye at targeted times in rye's growth cycle. This study addressed the weed suppression ability of rye (*Secale cereale* L.) cover crop by manipulating allelochemical production. Manipulation was achieved by damaging rye foliage and measuring the effect of the resulting allelopathic increases on weed suppression and subsequent crop yield in a tomato production system.

As a cover crop, rye scavenges soil nutrients during the non-cropping season, conserves soil moisture, and provides weed suppression. Rye residue suppresses weeds through the considerable biomass it accumulates early in the growing season. This residue provides a physical barrier (Teasdale, 1998) as well as chemical barrier (Barnes et al., 1987; Shilling et al., 1985; Creamer et al., 1996) against weed germination and growth.

Rye residue can suppress weeds from 30 to 75 days (Masiunas et al., 1995; Putnam, 1986). This period of suppression coincides with the presence of the allelochemicals cyclic hydroxamic acids (Hx) in the residue more than it does with the presence of the residue itself (Yenish et al., 1995; Burgos et al., 1999). As such, weed suppression may be enhanced by increasing endogenous levels of Hx or by extending the period in which the rye plant produces them.

These chemical compounds act in maize, wheat, and rye (Gramineae) as the major chemical defense compounds against insects and diseases. In undamaged rye, these compounds are in a non-toxic glucoside form of the hydroxamic acid 2,4-dihydroxy-1,4-benzoxazin-3-one (DIBOA-glucoside) (Neimeyer, 1988). When rye is damaged by insect or pathogen attack, DIBOA is activated and is eventually degraded to 2-benzoxazolinone (BOA) (Neimeyer, 1988; Collantes et al., 1999). During the vegetative stage of rye's life cycle, DIBOA and BOA are found in shoots, roots, and root exudates (Barnes et al., 1987; Pérez and Orneño-Nuñes, 1991; Collantes et al., 1997; Collantes et al., 1999). Collantes et al., 1999 have shown that the quantities of Hx allocated to shoots, roots, and root exudates in greenhouse-grown rye seedlings can be manipulated through consecutive defoliation of the shoot, which mimics grazing.

This project tested whether mowing rye in the field and allowing it to re-grow before killing it by sickle bar mowing could increase its allelopathic activity, and result in a decrease in weed germination and growth. Part I of this project, reported in OFRF's *Information Bulletin* 2004 (No. 13), determined the optimum time to mow rye in order to increase its allelopathic activity. Results of that study showed that targeting early spring for mowing when rye breaks dormancy is more effective in reducing redroot pigweed emergence than mowing in autumn before winter dormancy sets in, or not mowing rye at all. The study also suggested that targeted mowing increases weed suppression by increasing the allelopathic activity of rye through activity in rye roots.

Given results of Part I, Part II was conducted to determine if spring mowing could reduce weed emergence sufficiently for a tomato crop to be more competitive and produce higher yields. This was done by mowing rye grown as a monoculture, and as a mixture with crimson clover, allowing it to regrow before killing it with a sickle bar mower, then transplanting tomatoes into it and into black plastic and fabric mulches. Crop yield in mowed and unmowed rye plots was compared to yield in black plastic mulch control. In order to determine the effect of allelochemicals in rye shoots compared to roots, a leached rye shoot treatment was added in which shoots were leached in water to remove allelochemicals . By leaching out the allelochemicals from the shoots, rye in these treatments had non-toxic shoots but toxic roots, and as such, provided information on the relative importance of rye roots and shoots in allelopathic activity. To examine whether the effect of rye on crop production was mediated by weed suppression, redroot pigweed (*Amaranthus retroflexus*) seeds were planted and their emergence monitored.

Methods and Materials:

This project was conducted on Jug Bay Market Garden, a certified organic farm in Upper Marlboro Maryland, in 2003 in cooperation with owners Scott and Tonya Hertzberg, and on an organic plot on Hayden Farm in Beltsville, a research farm of the University of Maryland in 2004. The experimental design was an incomplete split-split plot design with cover crops and black mulch as whole plots arranged in complete block design with four blocks (Fig. 1). Whole plots were either black plastic mulch as a control, black fabric mulch, unleached rye, leached rye, and a rye-crimson clover mixture. Each whole plot of cover crops was divided into two split plots of different mowing treatments. Mowing treatments were unmowed (UM) and mowed (M). Since mowing treatments are irrelevant to plastic and fabric mulch treatments, these whole plots were not split but were considered equivalent to the unmowed (UM) split plots. As such, the design is an incomplete design with respect to the mowing split plot factor. Each of the (un)mowed split plots was randomly divided into two split-split plots, one with redroot pigweed seeds (+W) and the other without pigweed seeds (-W).

Prior to cover crop planting and black mulch placement, fields were chisel plowed and disked. Seeds of rye “Wheeler” (120 lb/A) and rye-crimson clover (60 lb/A rye, 20 lb/A clover) were scattered on October 26, 2002, and October 20, 2003 in beds 4ft wide, in which cover crop whole plots were 4ftx16ft. Black mulch treatments were placed on their respective whole plots of 4ft X 8ft at the time of rye sowing. The mowing treatment (M) was applied in the first week of April using a lawn mower, which cut cover crops in the mowed split plots to a height of 4in. Each (un)mowed split plot was 2ftx16ft. Rye roots and shoots from each (un)mowed split plot were sampled 7 days after the mowing treatment was applied for bioassays and chemical analysis. Roots sampled at this time were rinsed to remove as much soil as possible. Rye harvested at this time will be referred to hereafter as spring-sampled rye. Cover crops were allowed to regrow until rye had passed the heading stage in May, at which time rye from leached rye whole plots was sickle bar mowed on May 22, 2003 and June 2, 2004, and the shoots were leached in water to remove allelochemicals.

For the leaching treatment, fresh field rye from each (un)mowed split plot was separately leached in 45gal containers for 3 days/cycles of leaching. Water was continually circulated throughout each cycle using 3 water pumps per container. Per day, shoots were drained, samples of leachate collected, and fresh water added. After the final leaching cycle, shoots were drained, air dried and placed back on the split plots from which they came. When the leached rye was placed back on these split plots, standing rye from unleached rye and rye-clover plots was sampled for bioassays, nitrogen analysis and biomass, and then sickle bar mowed. Samples collected at this time will be referred to hereafter in this report as summer-sampled rye. Unlike spring-sampled rye, only shoots were collected during this summer sampling.

Prior to tomato transplanting, drip tape was installed under the cover crops and black mulch as part of a trickle irrigation system. Tomato transplants of the variety “Mountain Supreme” were transplanted into the beds on June 2, 2003 and June 28, 2004 in two rows per bed with 2.5 ft between rows. Spacing between plants within a row was 24in in 2003, and 36in in 2004. Tomatoes were transplanted such that each (un)mowed split plot contained 2 pairs of tomato plants from which data would be collected. Two weeks after tomato transplanting, each pair of tomato plants was randomly assigned to a weed split-split plot. One split-split plot received 200 redroot pigweed seeds that were scattered between the pair of tomatoes in an area of 1ftx2ft (+W). The second split-split plot with the other pair of tomato plants remained free of pigweed seeds (-W). Tomatoes were fertilized biweekly with Neptune’s Harvest fish emulsion, 2-4-2, applied through the irrigation system. Champion WP (Copper Hydroxide) was applied biweekly at a rate of 1Tbl/ gal. Pest control consisted of hand removal of Lepidopteron larvae, and applying Diatect V (pyrethrin) as the need arose at a rate of 4Tbl/gal.

To determine the effect of cover crop and black mulch on tomato production, biomass and fruit weight (yield) were quantified. Plant biomass was estimated by measuring height and diameter of tomato plants in a non-destructive method following Williams et al. 1998, and calculating cylindrical plant volume as a surrogate of above-ground plant biomass. To assess the effect of cover crop and black mulch on pigweed germination, pigweed seedling emergence was measured throughout the season.

Bioassay of Allelopathic Activity:

Spring-sampled rye shoots and roots, and summer-sampled rye shoots were bioassayed for allelopathic activity against redroot pigweed seeds. Rye residue from leached rye plots was bioassayed before the leaching process (spring-sampled) and after leaching (summer-sampled). To test for allelopathic activity, 15mg of oven-dried ground rye roots or shoots were placed in a petri dish under 2 filter papers. The control for rye residue contained 5 filter papers in a dish to mimic the residue's absorption of water. Filters were moistened with distilled water and 5 pigweed seeds were placed in each dish with 4 replicates per treatment.

Leachates collected during the leaching process were also bioassayed. Leachates were kept at –4 °F until processing, thawed, and then filtered before adding to petri dishes. Approximately 14ml of leachate were added to a petri dish in aliquots of 5ml and allowed to evaporate. The control for leachates consisted of a petri dish with filter paper only. Filters were moistened with distilled water and 5 pigweed seeds were placed in each dish with 4 replicates per treatment.

All dishes were covered, sealed with parafilm, and placed in a growth chamber at a temperature of 86°F day/ 77°F night, with a photoperiod of 16 hrs. light/ 8 hrs. dark for 3 days. Pigweed seeds were scored for germination, and are presented as percentage of control.

Chemical Analysis:

Rye roots and shoots were analyzed for BOA using High Performance Liquid Chromotography (HPLC) according to Collantes et al. 1997, and 1999.

Statistical Analysis:

Rye biomass and nitrogen concentration data were analyzed by Analysis of Variance (ANOVA) as a split plot complete block model with cover crop as the main factor and mowing as the split plot factor. Nitrogen concentrations were arcsine transformed before analysis, but are presented in tables in the untransformed form.

Bioassays of rye sampled after spring mowing (i.e. spring-sampled rye) were analyzed separately from summer-sampled rye to examine differences between rye roots and shoots. To examine the effect of leaching, summer-sampled rye was analyzed with leachates. Finally, shoots of spring-sampled and summer-sampled rye were analyzed together to examine seasonal differences in shoot allelopathic activity. Pigweed germination data were arcsine transformed and then analyzed as a split-split plot complete block design with cover crop as the main factor, mowing as the split plot factor, and plant part (shoot and roots) or date of sampling as split-split plot factor. Data are presented in the untransformed form.

Tomato biomass and yield data were analyzed by ANOVA as an incomplete split-split block design with cover crop and black mulch as the main factor, mowing as the split plot factor, and weeds as the split-split plot factor. Field pigweed emergence data were analyzed by ANOVA as an incomplete split plot block design with cover crop and black mulch as the main factor, and mowing as the split plot factor. Pigweed emergence data were square root transformed for analysis, but are presented in figures as untransformed data. In all analyses with incomplete designs, main, simple, and interactive effects were estimated at the levels of factors present using contrasts.

Data from each year were analyzed separately. Comparisons between treatments were done using the Least Square Differences (LSD) method. All analyses were carried out using the Proc Mixed procedure of SAS version 8.2, SAS Institute Inc., Cary, NC, USA.

Results & Discussion:

Rye biomass at the time rye was killed within each year was not significantly different between unleached rye, and rye-clover plots (t_6=1.6, P=0.16, 2003; $t_{11.9}$=1.52, P=0.15, 2004). However, in all cover crop plots, rye biomass was greater in the first year than the second (Table 1). In both years, mowing did not significantly affect biomass accumulation in any cover crop plot (Table 1, F=0.03, P=0.8, 2003; F=0.12, P=0.7, 2004). The leaching process did reduce rye biomass in 2004 such that leached rye plots (1327 lb/A) contained less residue when compared to unleached rye (6511 lb/A), or rye-clover plots (5095 lb/A) ($t_{11.9}$=-5.58, P=0.0001; $t_{11.9}$=-4.06, P=0.001, respectively).

Nitrogen concentrations in summer-sampled rye showed no significant differences between rye in the different cover crop whole plots in either year. In addition, mowing did not significantly affect nitrogen concentrations (Table 2, F=3.05, P= 0.09, 2003; F=1.12, P=0.3, 2004). Similar to biomass data, nitrogen concentration in rye shoots was higher in 2004 than 2003.

Rye biomass and tissue nitrogen content differences seen between the two years may be due to site-specific differences. The site for 2003 was sandy loam with 2.1% organic matter, while the site for 2004 was loam with 3.4% organic matter. Soil nitrate content at the time rye was killed (summer) in 2003 was lower than 2004 (Table 3). In 2003, there was no significant difference in soil nitrate levels between cover crop plots and black mulch plots (F=1.18, P=0.34) with the exception of fabric mulch (2.5 ppm) which had marginally lower nitrate levels than unleached rye (4.3 ppm) and rye-clover plots (4.6 ppm) (t_{27} =1.78, P=0.086; t_{27}= -2.11, P= 0.045, respectively). In 2004, soil nitrate was significantly higher in black plastic and fabric mulch (21.5 ppm) than in cover crop plots (11.95 ppm)(t_{24}=5.16, $P<0.0001$). These results may be explained by the higher biomass of rye in 2004 (5803 lb/A) than that in 2003 (747 lb/A). The higher soil fertility in Hayden Farm in 2004 allowed more biomass accumulation in rye and thus more nitrogen scavenging from the soil in the cover crop plots relative to the black mulch plots. In contrast, the lower soil fertility of Jug Bay Market Garden in 2003 did not support high biomass accumulation and thus nitrogen scavenging was not significant, resulting in similar soil nitrate levels between cover crops and black mulch plots. In both years, mowing rye did not affect soil nitrate levels.

Bioassays on redroot pigweed seeds using spring-sampled rye shoots and roots showed that in all cover crop plots, rye shoots (3%, 2003; 21%, 2004) significantly inhibited pigweed germination more than roots (69%, 2003; 66%, 2004) in both years (F=73.33, $P< 0.0001$, 2003; F=50.29, $P<0.0001$, 2004). However, there was no significant difference in pigweed germination in spring-sampled rye between mowed and unmowed rye plots in either year (Table 4). These results correspond with results of chemical analysis for the levels of hydroxamic acids in rye shoots and roots sampled 7 days after mowing from unleached rye plots. While there was a significant difference in Hx between roots (0.06%) and shoots (0.12%) (Fig.2, F=31, P=0.0003), there was no significant difference in Hx levels between mowed (0.08%) and unmowed (0.09%) rye (F=0.56, P=0.47).

In general, bioassays of rye shoots showed that shoots from 2004 were less toxic than 2003 (Table 5). This was seen in unleached rye shoots of the two years; less pigweed seeds germinated in bioassays using unleached shoots from 2003 (4%) than unleached shoots of 2004 (24.5%). When comparing pigweed germination in 2003 spring-sampled unleached shoots (2%) to that in summer-sampled unleached shoots (6%), there was no significant seasonal difference in germination (Table 5, t_{18}=-0.77, P= 0.45). Both spring- and summer-sampled rye showed significant germination suppression with averages not significantly different from zero ($t_{34.1}$= 4.53, P= 0.6; $t_{34.1}$=1.45, P= 0.16 respectively). These results were similar to results of bioassays using 2004 unleached rye. In contrast, spring-sampled rye shoots from rye-clover plots (3%) were significantly more inhibitory than summer-sampled shoots (18%) from these plots (t_{18}=-3.05, P= 0.0007), with only pigweed in summer-sampled rye showing any significant germination ($t_{34.1}$=4.53, P<0.0001). This suggests that nitrogen provided by clover throughout the spring until rye was killed in the summer may have reduced the inhibitory effect of rye on weed germination. However, bioassays of 2004 rye from rye-clover plots lacked the seasonal difference in allelopathic activity seen in 2003 rye bioassays. This may be due to the higher overall soil fertility of the 2004 site, in which the effect of nitrogen-supplying clover was not detected due to an abundance of nitrogen in the spring and summer of 2004.

In bioassays using 2003 rye shoots from leached rye plots, germination in spring-sampled rye that had not been leached yet (4%) was significantly lower than that in summer-sampled rye that was leached (27%) (Table 5, t_{18}=-4.54, P= 0.0003), with only summer-sampled rye showing any significant germination ($t_{34.1}$=6.60, P< 0.0001). This suggests that leaching did reduce allelopathic activity. This is further supported when comparing bioassays of rye from unleached rye plots to those from leached rye plots. Pigweed germination in spring-sampled rye shoots from unleached rye plots (2%) was not significantly different from that in spring-sampled rye from leached rye plots (4%) ($t_{34.1}$=-0.33, P= 0.74), while germination in summer-sampled rye from unleached rye plots (6%) was lower than that in summer-sampled rye from leached rye plots (27%) ($t_{34.1}$= 3.64, P= 0.0009). In addition, comparisons between leachates and shoots showed that germination in leachates was significantly higher than that in rye shoots (data not shown). These results were similar in 2004. Bioassays of spring-sampled rye from leached plots (18%) showed more inhibition of pigweed seed germination than summer-sampled rye shoots from these leached plots (43%). Moreover, comparison between bioassays of summer-sampled unleached rye and leached rye of 2004 showed significantly more inhibition in unleached rye (20%) than leached rye (43 %), suggesting that leaching reduced inhibitory allelochemicals in 2004 as well. These results suggest that a substantial part of rye's allelopathy was from activity in shoots and that leaching allelochemicals reduced allelopathic activity of shoots.

The effect of mowing rye on allelopathic activity in shoots was seen in bioassays of rye from rye-clover plots (Fig.3). Spring-sampled unmowed shoots (4%) were significantly more inhibitory than summer-sampled unmowed shoots (26%) (t_{18}=-3.10, P=0.006), suggesting that allelopathic activity in unmowed rye from rye-clover plots decreased throughout spring. In contrast, in bioassays of mowed shoots taken from rye-clover plots, pigweed germination was not significantly different between spring-sampled (2%) and summer-sampled shoots (11%) (t_{18}=-1.21, P=0.24). This suggests that mowing the rye-clover mixture maintains rye's allelopathic activity longer than not mowing the mixture.

The effect of mowing rye in pigweed germination bioassays was also seen in summer-sampled unleached shoots, and shoots from rye-clover plots (Fig. 3). In 2003, germination in unmowed shoots (17%) was marginally higher than mowed shoots (7%) (t_{34}=-1.73, P=0.09). Although this mowinginduced suppression was not statistically significant in 2004 (t_{33}=-0.81, P=0.42), it showed the same pattern; germination in unmowed shoots (22%) was higher than that in mowed shoots (15%). However, given that mowing did not change Hx levels, the difference between pigweed germination in mowed and that in unmowed shoots from summer-sampled unleached rye and rye-clover mixture was not mediated by differences in hydroxamic acid levels.

To test the effect of mowed rye on weeds in the field, redroot pigweed emergence within the weed split-split plots was measured. In both years there was significantly less pigweed seedlings in all cover crop plots when compared to seedlings in plastic mulch (Fig. 4, P<0.0001), but with no effect of mowing rye on rates of emergence. While percent germination in black mulch was 8% in 2003 and 14% in 2004, average pigweed germination rates in cover crops were 1.2% in 2003 and 0.8% in 2004. This suggests that pigweed pressure was too low to detect any effect of mowing rye on pigweed emergence in the fields of either year.

However, there were significant differences in tomato biomass between cover crops and the black mulch control in 2003 (Fig. 5). Moreover, the effect of mowing rye differed between cover crop treatments. Tomato biomass in unmowed unleached rye plots ($20x10^4$ cm^3) was significantly lower than that in plastic mulch control ($29x10^4$ cm^3) ($t_{18.9}$= 2.45, P=0.02), while biomass levels in mowed unleached plots ($23x10^4$ cm^3) were not significantly different from those in the plastic mulch control ($t_{18.9}$=1.62, P=0.12). In contrast, biomass in unmowed rye-clover plots ($23x10^4$ cm^3) was at the level of plastic mulch controls ($29x10^4$ cm^3) ($t_{18.9}$= 1.58, P=0.13), while biomass in mowed rye-clover plots ($16x10^4$ cm^3) was significantly lower than that in the plastic mulch control ($t_{18.9}$= 3.33, P= 0.003). These patterns were not seen in leached rye plots; biomass in both unmowed ($15x10^4$ cm^3) and mowed ($15x10^4$ cm^3) leached plots was significantly lower than the plastic mulch control ($29x10^4$ cm^3) ($t_{18.9}$= -3.58, P=0.002, $t_{18.9}$= -3.56, P=0.002, respectively).

Tomato yields were also affected by mowing cover crops in 2003 (Fig.6). Yields in unmowed unleached rye plots (1.5 lb/plant) were significantly lower than those in the plastic mulch control (4 lb/plant) (t_{21}= 2.74, P=0.01), while yields in mowed unleached plots (2.6 lb/plant) were not significantly different from the plastic mulch control (t_{21}= 1.45, P=0.16). In contrast, yields in unmowed rye-clover plots (2.6 lb/plant) were not significantly different from the plastic mulch control (4 lb/plant) (t_{21}= 1.5, P=0.15), while yields in mowed rye-clover plots (1 lb/plant) were significantly lower than those in the plastic mulch control (t_{21}= 3.38, P= 0.003). Yields in leached rye plots showed similar patterns to those seen in growth data. Yields in unmowed (1.3 lb/plant) and mowed (1.3 lb/plant) leached rye plots were significantly lower than those in plastic mulch controls (4 lb/plant) (t_{21}= -3, P= 0.007; t_{21}= -3.04, P=0.006) and at the levels of unmowed unleached rye plots (1.5 lb/plant). These results suggest that mowing rye that is grown as a monoculture can increase tomato production. The negative effect of mowing rye that is grown as mixture with crimson clover suggests that a nitrogen-supplying legume may counter the mowing effect. As such, soil fertility may be the component affecting rye's response to mowing.

The suggested involvement of soil fertility in rye's response to mowing is supported by data collected in 2004. The site for 2004 had a higher % organic matter than the site for 2003. This, coupled with higher clay content of the soil in the 2004 site, may have allowed more nutrients to be retained in the soil for use by the crop. In general, tomato production in 2004 was 2 folds higher than production in 2003 (Fig. 7), with no significant differences in yields between any of the cover crop or black mulch plots.

Finally, there was no effect of planted redroot pigweed seeds on tomato production in any cover crop plot of either year. Weeds in 2003 did significantly reduce tomato biomass in fabric mulch in (t_{24}= -2.75, P= 0.01) but not in plastic mulch (t_{24}= 0.76, P=0.45). However, the effect of weeds in fabric mulch did not extend to tomato yields. In 2004, weeds significantly reduced tomato growth early in the season (1 WAP) in cover crop plots, but this difference disappeared later in the season (4 WAP), and was not seen in the tomato yield data. This suggests that the effect of weeds early in the season may have no effect on crop yield if weed pressure is as low as was the case for the experimental pigweed.

Conclusion:

Given low redroot pigweed germination levels in both years, a reduction in competition between tomato plants and the emerging redroot pigweed was not the likely cause of increases in tomato yield in mowed rye plots grown a monoculture (unleached rye). The increase in tomato production may be due to a reduction in natural populations of weeds in the mowed plots, not the experimental weeds that were planted.

Natural weeds were allowed to grow in the tomato beds in 2003 more than in 2004 due to time constraints in maintaining beds free of all non-experimental weeds. In general, these weeds tended to be grasses. In 2004, there were less natural weeds and consequently less competition between the crop and weeds. Moreover, in both years data were collected from 2 tomato plants in each weed plot. However in 2003, one border tomato plant was planted on either side of the pair of plants from which data were collected. These border plants were to control for border effects within each weed plot. As a result, in 2003 each weed plot had 4 tomato plants. In 2004, due to limited availability of seeds for the variety used (Mountain Supreme) only the experimental pair of tomato plants was planted in each of the weed plots, reducing the number of tomato plants in 2004 to 2 in each weed plot. Therefore in general, there was more competition among tomato plants in 2003 than 2004.

The increase in competition among tomato plants and between natural weeds and tomato plants, coupled with the reduced resource availability seen in the sandy loam site of 2003 may have resulted in increasing allelopathic activity of rye such that mowing provided a competitive advantage to the tomato crop. This is supported by the results of bioassays in which rye from 2003 plots was more inhibitory than rye from 2004 plots. As such, the decrease in competition and the increase in soil fertility levels in 2004 provided adequate resources for a high crop production that masked the effect of not only mowing rye, but of cover crops in general. I will be testing this hypothesis further by monitoring natural populations of weeds in mowed versus unmowed rye, as well as examining the effect of soil fertility on vegetable production in mowed rye.

The role of soil fertility in rye's allelopathic response to mowing should be examined for two reasons. The results of this project suggest that mowing rye is more effective in increasing crop production in soils with low resources. However, there is need to examine how and why soil fertility affects rye's response to mowing in order to apply this management method on a broader scale.

Further study of rye mowing and soil fertility is also necessary because growing cover crops as mixtures is common practice. The current study's results in plots containing rye and crimson clover suggest that the addition of a nitrogen producing cover crop can affect the response of rye to mowing. This may be due to the added nitrogen provided by the legume, or it may be due to soil organisms that are associated with the legume that can metabolize the allelochemicals. As such, targeted mowing may be most beneficial to farmers using rye as a monoculture. Without further investigating the effects of rye mowing in cover crop mixtures, mowing rye in a mixture is not recommended when rye is grown in combination with legumes. I will be further testing the effect of mowing rye on weed suppression in various cover crop mixtures and its resulting effect on crop production.

In conclusion, targeted mowing of rye cover crop as a monoculture appears to provide a competitive advantage to a cash crop grown in a resource-limited environment. The results of Jug Bay Market Garden, formerly a tobacco farm, exemplify the beneficial potential of targeted mowing in former tobacco farms of the Mid-Atlantic States. Since rye is regularly used to reconstitute soils, targeted mowing may be most effective in reclaiming resource-depleted farms that have been cultivated for generations.

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References:

Barnes, J.P., A.R. Putnam, A.R. Burke, and J. Aasen. 1987. Isolation and characterization of allelochemicals in rye herbage. Phytochemistry 26:1385-1390

Burgos, N.R., R.E. Talbert, and J.D. Mattice. 1999. Cultivar and age differences in the production of allelochemicals by *Secale cereale.* Weed Science 47:481-485

Collantes, H.G., E. Gianoli, H.M. Niemeyer. 1997. Effect of defoliation on the patterns of allocation of hydroxamic acid in rye (*Secale cereale*). Envir. Exper. Bot. 38:231-235

Collantes, H.G., E. Gianoli, H.M. Niemeyer. 1999. Defoliation affects chemical defenses in all plant parts of rye seedlings. J. Chem. Ecol. 25:491-499

Creamer, N.G., M.A. Bennett, B.R. Stinner, J. Cardina, and E.E. Regnier. 1996. Mechanisms of weed suppression in cover crop-based production systems. HortScience 31:410-413

Masiunas, J.B., L.A. Weston, and S.C. Weller. 1995. The impact of rye cover crops on weed populations in a tomato cropping system. Weed Science 43:318-323

Niemeyer, H.M. 1988. Hydroxamic acids (4-Hydroxy-1, 4-Benzoxazin-3-ones), defense chemicals in the Gramineae. Phytochemistry 27:3349-3358

Pérez, F.J., and J. Ormeño-Nuñez. 1991. Difference in hydroxamic acid content in roots and root exudates of wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.): Possible role in allelopathy. J Chem. Ecol. 17:1037-1043

Putnam, A.R. 1986. Allelopathy: Can it be managed to benefit horticulture? HortScience 21:411-413

Shilling, D.G., R.A. Liebl, and A. D. Worsham. 1985. Rye (*Secale cereale* L.) and wheat (*Titicum aestivum* L.) mulch: The suppression of certain broadleaved weeds and the isolation and identification of phytotoxins. In: *The Chemistry of Allelopathy,* ed. A.C. Thompson. American Chemical Society, Washington, D.C. pp.243-271

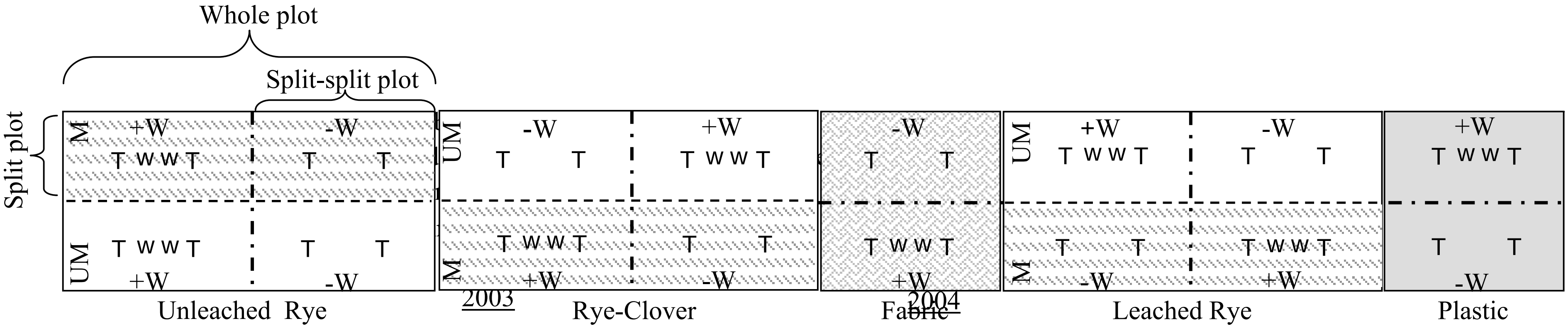
Teasdale, J.R. 1998. Cover crops, smother plants, and weed management. In: *Integrated Weed and Soil Management*, eds. J.L. Hatfield, D.D. Buhler, and B.A. Stewart, Ann Arbor Press, Michigan, pp. 243-270

Williams II, M.M., D.A. Mortensen, J.W. Doran. 1998. Assessment of weed and crop fitness in cover crop residue for integrated weed management. Weed Science 46:595-603

Yenish, J.P., A.D. Wosham, and W.S. Chilton. 1995. Disappearance of DIBOA-glucoside, DIBOA, and BOA from rye (*Secale cereale* L.) cover crop residue. Weed Science 43: 18-20

Addenda

Included in this final report are photos of the project at Jug Bay Market Garden in Upper Marlboro, Maryland, and Hayden Farm at the University of Maryland.



Cover Crop	2003 UM	2003 M	2004 UM	2004 M
Rye	873 ± 114a	752 ± 88a	6680 ± 1073a	6342 ± 507a

Figure 1: Experimental design showing a block (bed) with cover crop and black mulch whole plots consisting of unleached rye, rye-crimson clover mixture, black fabric mulch, leached rye, and black plastic mulch plots. (Un)mowed split plots consisted of unmowed (UM) and mowed (M) plots. Weed split-split plots were with weeds (+W), and without weeds (-W) plots. Tomato plants (T) were paired in each weed plot with weeds scattered between a pair in (+W) plots.

Table 1: Cover crop biomass (lb/A) in (un)mowed plots.
Cover crops included unleached rye (Rye), rye from rye-clover (Rye-mix),
clover from rye-clover (Clover-mix), and leached rye .
Mowing treatments included unmowed (UM), and mowed (M).

	2003		2004	
Cover Crop	UM	M	UM	M
Rye	873 ± 114a	752 ± 88a	6680 ± 1073a	6342 ± 507a
Rye-mix	658 ± 32a	705 ± 178a	5270 ± 1640a	4920 ± 819a
Clover-mix	119 ± 28b	222 ± 32b	301 ± 211a	289 ± 121a
Leached Rye			1303 ± 85b	1351 ± 48b

Means±se with different letters within each year are significantly different at P< 0.001 (2003), and P< 0.004 (2004)

Table 2: Percent nitrogen in summer-harvested cover crop shoot tissue in (un)mowed plots.
Cover crops included unleached rye (Rye), rye from rye-clover (Rye-mix),
clover from rye-clover (Clover-mix), and leached rye .
Mowing treatments included unmowed (UM), and mowed (M).

	2003		2004	
Cover Crop	UM	M	UM	M
Rye	1.03 ± 0.08a	1.19 ± 0.08a	0.63 ± 0.08a	0.73 ± 0.09a
Rye-mix	1.03 ±0.1a	1.17 ± 0.2a	0.69± 0.05a	0.70 ±0.07a
Clover-mix	1.85 ± 0.1b	1.93 ± 0.1b	-	-
Leached Rye	0.96 ± 0.1a	1.01± 0.07a	0.60 ± 0.06a	0.60 ± 0.03a

Means±se with different letters within each year are significantly different at P< 0.0001 (2003).

Table 3: Soil nitrate (ppm) in (un)mowed plots within cover crops and mulch whole plots before tomato planting.
Plots included unleached rye (Rye), rye-clover, leached rye, plastic mulch, and fabric mulch.
Mowing treatments included unmowed (UM), and mowed (M).

	2003		2004	
Cover Crop	UM	M	UM	M
Rye	4.55 ± 0.8a	4.02 ± 0.9ab	11.5 ± 2.5a	11.7 ± 3.1a
Rye-clover	5.5 0 ± 0.5a	3.72 ± 0.7ab	12.3 ± 2a	12.3 ± 2.1a
Leached Rye	3.62 ± 0.82ab	4.75 ± 1.2ab	10.5 ± 1.3a	12.8 ± 0.9a
Plastic	4.12 ± 0.9ab	-	21.9 ± 4.5b	-
Fabric	2.50 ± 0.2b	-	21.1 ± 2.0b	-

Means±se with different letters within each year are significantly different at P≤ 0.001

Table 4: Percent germination of redroot pigweed in bioassays of rye shoots and roots harvested after mowing (Spring-sampled). Rye was taken from unleached rye (Rye), rye-clover (Rye-mix), and leached rye plots. Mowing treatments included unmowed (UM), and mowed (M).

	2003				2004			
	Shoot		Root		Shoot		Root	
Cover Crop	UM	M	UM	M	UM	M	UM	M
Rye	0a	4 ± 4a	55 ± 5.3b	78 ± 14b	32 ± 9ac	27 ± 12a	77 ± 16b	56 ± 7bc
Rye-mix	4 ± 4a	4 ± 4a	67 ± 22b	79 ± 14b	11 ± 2a	20 ± 6a	64 ± 11b	60 ± 19b
Leached Rye*	8 ± 6a	0a	66 ± 24b	67 ± 16b	15 ± 4a	22 ± 10a	73 ± 15b	65 ± 12b

Means±se with different letters within each year are significantly different at $P \leq 0.05$

* Spring-harvested rye from leached rye plots is equivalent to unleached rye (Rye).

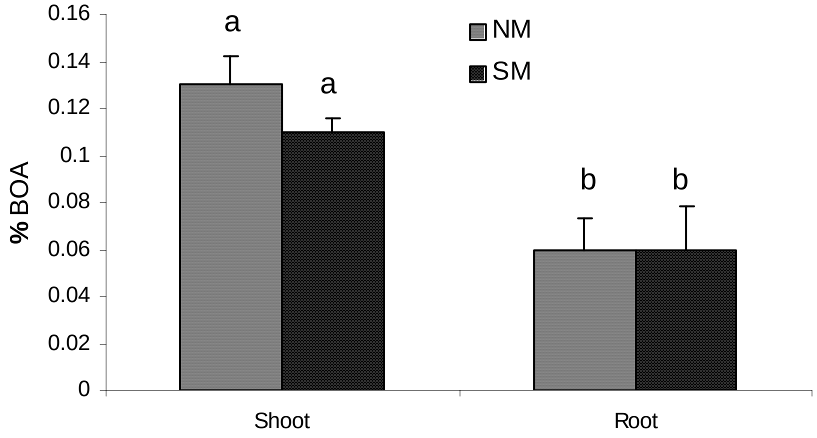


Figure 2: Hydroxamic acid levels in unleached rye sampled after spring mowing. Mowing treatments were unmowed (UM), and mowed (M). Means with different letters are significantly different at P<0.001.

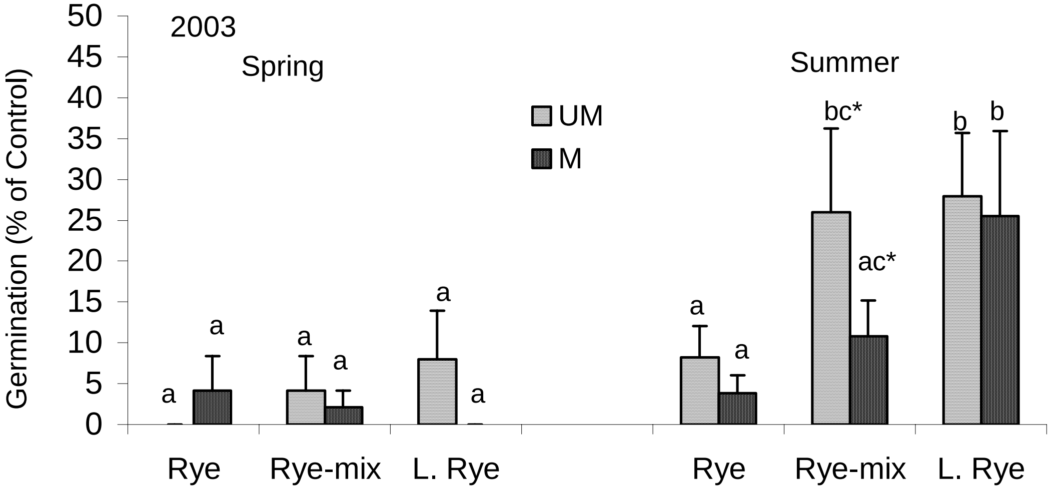


Figure 3: Effect of mowing on redroot pigweed germination in bioassays of spring-harvested (Spring), and summer-harvested (Summer) 2003 rye shoots from: unleached rye (Rye), rye-clover mixture (Rye-mix), and leached rye (L. Rye). Mowing treatments were unmowed (UM), and mowed (M). Means with different letters within each year are significantly different at $P<0.05$. *means with (c) are marginally different at $P=0.06$.

Table 5: Percent germination of redroot pigweed in bioassays of rye shoots harvested 7 days after mowing (Spring-sampled), and after sickle bar mowing (Summer-sampled). Rye was taken from unleached rye (Rye), rye-clover (Rye-mix), and leached rye plots.

	2003		2004	
Cover Crop	Spring	Summer	Spring	Summer
Rye	2 ± 2a	6 ± 2a	29 ± 7ac	20 ± 2a
Rye-mix	3 ± 2a	18 ± 6b	16 ± 3a	17 ± 4a
Leached Rye*	4 ± 3a	27 ± 6b	18 ± 5a	43 ± 9bc

Means±se with different letters within each year are significantly different at $P \leq 0.05$

* Spring-harvested rye from leached rye plots is equivalent to unleached rye (Rye).

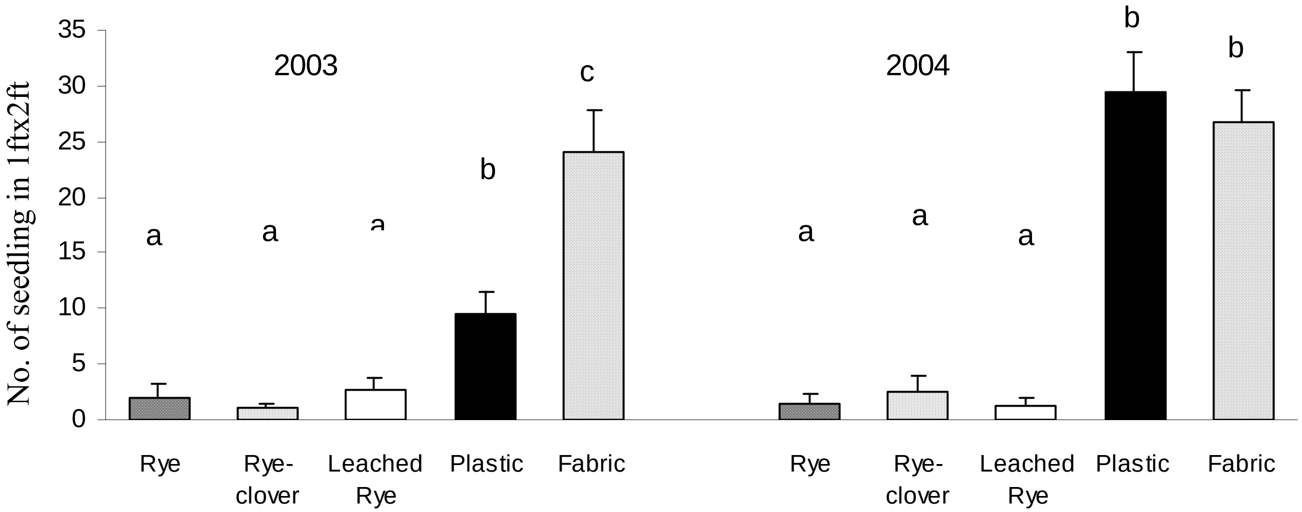


Figure 4: Pigweed emergence in the field in cover crops and mulch 6 weeks after planting. Cover crop treatments were unleached rye (Rye), rye-clover mixture, and leached rye. Means with different letters within each year are significantly different at $P<0.01$.

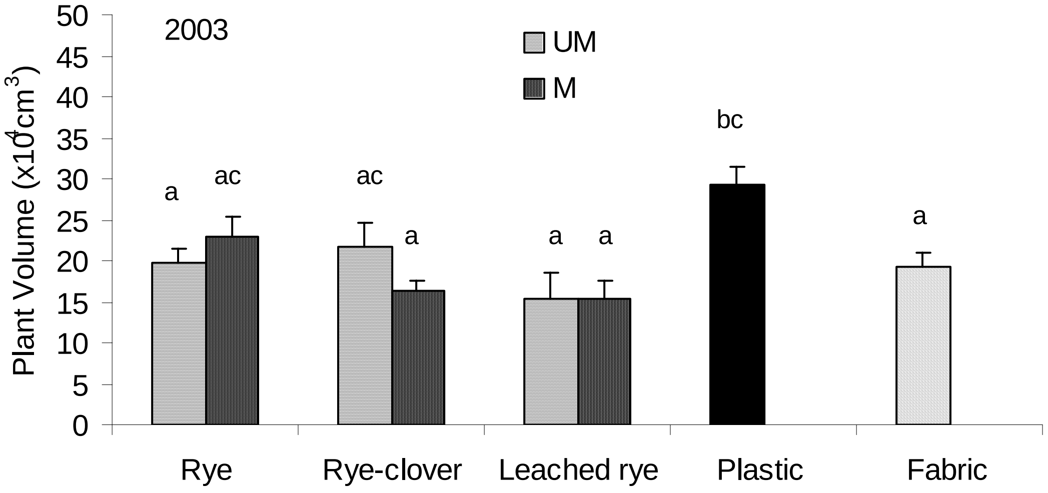


Figure 5: Effect of mowing on tomato plant biomass (cm^3) in 2003 in unleached rye (Rye), rye-clover mixture, leached rye, plastic and fabric mulch plots. Mowing treatments were unmowed (UM), and mowed (M). Means with different letters within each year are significantly different at P<0.05.

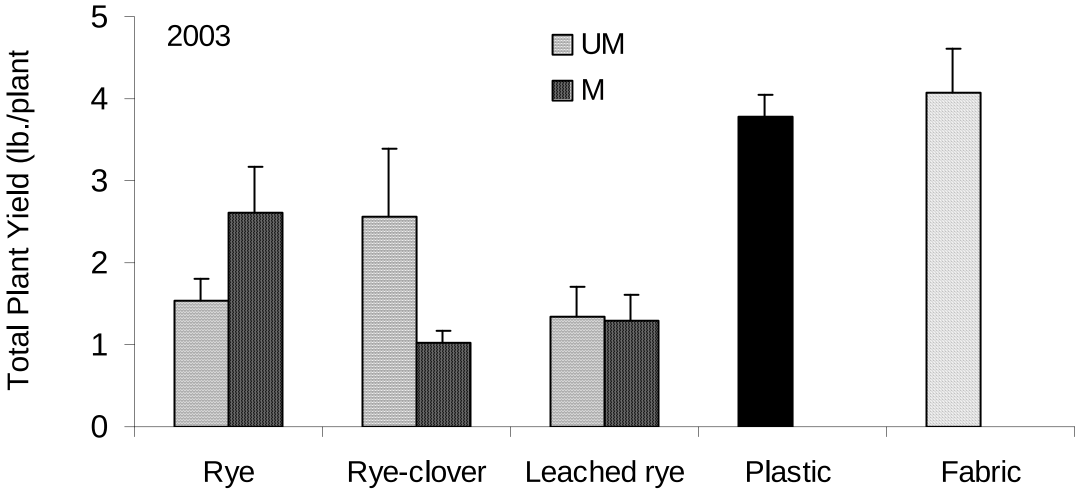


Figure 6: Effect of mowing on tomato plant yield (lb/plant) in 2003 in unleached rye (Rye), rye-clover mixture, leached rye, plastic and fabric mulch plots. Mowing treatments were unmowed (UM), and mowed (M).

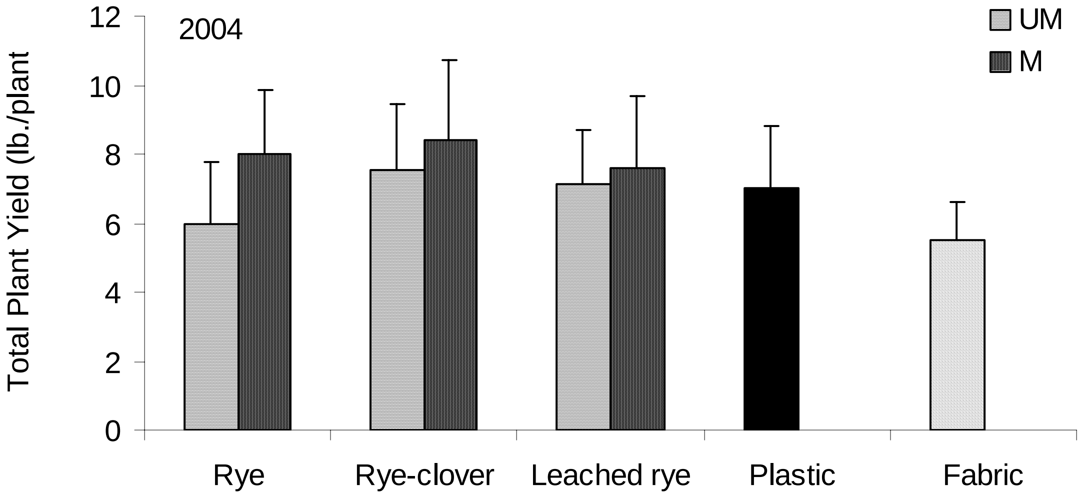


Figure 7: Effect of mowing on tomato plant yield (lb/plant) in 2004 in unleached rye (Rye), rye-clover mixture, leached rye (L. Rye), plastic and fabric mulch plots. Mowing treatments were unmowed (UM), and mowed (M).

4 3'03

Spring mowing at Jug Bay Market Garden in Upper Marlboro, MD, 2003.

4 7'04

Blocks showing unmowed (green), and mowed (yellow green) split plots at Hayden Farm in Beltsville, MD, 2004

5 28'03

Air-drying leached rye before returning it to the field

7 1'04

Blocks showing whole plots of black plastic and fabric mulches, leached rye (light colored rye), unleached rye, and rye-clover. Tomatoes were planted in 2 rows per block/bed.

7 22 '04

Weed split-split plots in black plastic mulch with a –W plot (background), and a +W plot (foreground). Redroot pigweed seeds were scattered in the open area of the mulch between tomato plants.

Weed split-split plots with +W plots (foreground, marked with black pegs) and –W plots (background) in a leached rye whole plot.

Addenda to *Targeted Mowing to Increase Allelopathy of Rye in a Tomato Production System*
By Neda Caster Diab, University of Maryland at College Park