Evaluation of Weed and Nutrient Management Practices in Organic Pear Orchards

Chuck Ingels
University of California Cooperative Extension
Sacramento, CA

Tom Lanini
Department of Plant Sciences, UC Davis
University of California
Davis, CA

Karen Klonsky and Rich Demoura
Agricultural and Resource Economics
University of California
Davis, CA

Ken Shackel
Department of Plant Sciences
University of California
Davis, CA

Abstract

From 2009-11, four weed control treatments (in-row mowing, landscape fabric, wood chips, and organic herbicide) and three fertilizer treatments (chicken manure at high vs. low rate, feather meal) were compared in an organic, no-till Bosc pear (*Pyrus communis*) orchard with solid-set sprinklers. Weed control in the landscape fabric and wood chip treatments was generally excellent, and multiple herbicide applications per year resulted in only partial control. There were no significant yield differences among treatments, and little difference in fruit diameter or weight. There were no significant differences in trunk growth between treatments. The wood chip treatment had significantly lower stem water potential than other treatments in August 2009 only. In two of the years, the N content of leaves in mow + no fertilizer was significantly lower than most high-rate manure treatments, and leaf P content followed the opposite trend. All fertilizer treatments tended to increase soil nitrate-nitrogen over non-fertilized plots. Soil phosphorus and potassium were highest under wood chips, and phosphorus was lower under feather meal. Soil pH was lowest under feather meal, and soil organic matter was highest under wood chips. Wood chips tended to have fewer vole holes than in-row mowing, and fabric tended to result in greater trunk damage by voles. Assuming that landscape fabric lasts 8 years, it is only slightly more expensive per year than in-row mowing alone. An organic herbicide program is more expensive because of the herbicide cost and the many applications required. Wood chips were by far the most expensive treatment because of the cost of chips and spreading them, as well as the need to reapply every year. The use of feather meal was about three times the cost of low-rate manure application for an equivalent amount of N.

INTRODUCTION

Organically grown tree fruits generally sell for a substantially higher price than conventional produce. Whether the price premium increases profitability depends on yields, fruit size, and fruit quality, and production costs. Successful organic production often requires more labor, bulkier fertilizers and amendments, and more monitoring than conventional production. In most years, growers find that control in-row weeds and providing sufficient nitrogen are the greatest challenges, and the two are linked. Surveys conducted in Washington have shown that the top three production issues in organic tree fruit production were crop load management, weed control, and soil fertility (Granatstein, 2003).

Organic Fertilizers

Organic fertilizers tend to have fairly low nitrogen (N) content. The most cost-effective fertilizer is often poultry manure, which usually includes wood shavings and/or rice hulls. It averages about 2-3% N, and also has phosphorus, potassium, calcium, and magnesium. Pelleted feather meal is often used because it is easy to spread; it usually has about 12% N, but is still much more expensive than poultry manure and other nutrients are lacking or present in lower amounts. Compost is an excellent soil amendment, but the N in it is released slowly over several years. To maintain organic certification, uncomposted manures may not be applied within 90 days of harvest.

A portion of the N contained in manure and compost will volatilize into the atmosphere as ammonia if not disked into the soil – as much as 30 percent of the N may be lost (Chaney et al., 1992). Most orchards use nontillage, so applied manure will lose N to the air, although may be lost if it is irrigated fairly quickly after application. Manure and compost release plant-available N at different rates, which is largely based on the C:N ratio – the lower the ratio, the faster the release. With poultry manure, the majority of the N will be available to plants in the first year; poultry manure also has the highest volatilization potential, as evidenced by the strong ammonia smell. The "decay series" of manures was studied by UC researchers in the 1970s (Pratt et al., 1973), and the proportion of N availability over a 3-year period (years 1, 2, and 3) was shown to be .90, .10, .05 for chicken, .75, .15, .10 for dairy, and .35, .15, .10 for feedlot.

Thus, 90% of the N in chicken manure would be mineralized in the first year. In the second year 10% of the residual N would be mineralized, and 5% of the residual would be mineralized in the third and subsequent years (Pang and Letey, 2000). These values may vary widely for any given manure based on many factors. Mineralization of N in composts is generally well below that of feedlot manure.

Organic In-Row Weed Management

The greatest concentration of tree roots is likely under the canopy in the tree row, so weeds in the tree row compete with trees for nutrients and water. This competition is especially problematic for young trees, but yields and fruit size of mature trees can also be reduced by in-row weeds, especially warm-season grasses.

Organic weed management practices include mowers and cultivators that move around trunks and sprinklers, organic herbicides, flame or steam weeders, geese or sheep, and organic and synthetic mulches. In-row mowers are generally cost effective, but weeds still grow and compete with trees for nutrients and water and weeds still provide habitat for voles. In-row cultivation can effectively control weeds, although tree roots near the surface can be damaged. Some implements, such as the Weed Badger, are hydraulically driven with a vertical axis cultivating head. Many organic tree crop growers in the Pacific Northwest use the Wonder Weeder, with simple rolling cultivators near the tree row and a spring blade that works in between the trunks.

Available organic herbicides, mostly based on clove oil, cinnamon oil, acetic acid, or citric acid, are effective mainly on very young weeds so they must be applied often, and they have limited efficacy on perennial weeds. Flame weeders are fairly effective on young weeds, but they often require multiple passes for some species, and they use substantial amounts of fuel. Sheep or geese can be very effective, and whereas they no longer must be removed 90 days before fruit harvest for organic certification, they do require fencing and they must be cared for and managed.

Mulches, either organic or landscape fabric, provide a practical but expensive method of preventing or greatly reducing weed growth in tree rows and potentially improving the nutrient and moisture status of trees. Wood chips add organic matter and nutrients but they are more effective against annual weeds than perennial weeds. They are also very expensive to purchase and apply.

A 2004-2006 Washington (USA) study showed that the total cost of applying a 5-foot wide, 6-inch thick layer of wood chips was $924/acre (Wiman et al., 2007). In that study, which compared two in-row tillage implements, in-row mowing, and wood chip mulch, wood chips provided the best weed control in all 3 years, although it needed reapplication in year 3. This treatment also produced the greatest tree growth and fruit size. In a related trial, a Gala apple block was used to compare a 4-inch wood chip mulch in the tree row with an herbicide strip (Granatstein and Mullinix, 2008). In the first year, mulched plots consistently had 15-20% higher soil moisture at the end of each irrigation cycle than the bare ground plots. In the second year, the two treatments were watered independently according to need, and mulching reduced cumulative irrigation application by 20-30 percent.

Synthetic fabric allows water penetration but it excludes light to act as an effective barrier to weed growth. A 3 to 4 ft. width of fabric is placed on either side of the row and they overlap and are pinned where they join. The outside edges are buried or pinned.

In a 5-year study begun in a newly-planted, conventional cherry orchard in Hood River, OR (USA), researchers reported over 30% greater tree growth and fruit yield where a 6-ft. wide, in-row strip of synthetic fabric was used compared to herbicide strip alone (Núñez-Elisea et al., 2005). Although the polypropylene mulch resulted in substantially increased costs in all 5 years, gross returns from fruit sales were 218 and 43% greater where mulch was used than non-mulched trees in the first 2 years of commercial harvest (years 4 and 5 of the study, respectively). Cumulative cash costs for the first 4 years before fruit production were $2,123/acre higher with mulch relative to no mulch; however, these costs were offset quickly by the increased returns from enhanced fruit yields.

MATERIALS AND METHODS

Treatments

This trial was initiated in fall 2008 in a Golden Russet Bosc pear block (planted in 2001) near Sacramento, CA (USA), and it will continue through 2011. Orchard spacing is 18 ft. between rows x 10 ft. between trees (242 trees/acre). The rootstock is Winter Nelis and the soil is Valpac loam. The orchard is irrigated by solid set sprinklers, and nontillage is used, with middles mowed periodically.

A randomized, complete block design was used, with 7 treatments and 5 replications. Each plot consisted of 6 trees. Each experimental block consisted of a single row, so each treatment was randomized down each of 5 rows. Annual treatments were as follows:

1. In-row mowing, no fertilizer
2. In-row mowing + chicken manure (~2 tons/acre)
3. In-row mowing + chicken manure (~4 tons/ acre)
4. In-row mowing + feather meal (~0.5 ton/ acre)
5. Landscape fabric + chicken manure (~4 tons/ acre)
6. Wood chips 4-6 in. + chicken manure (~4 tons/ acre)
7. In-row mowing + herbicide strip (acetic acid) + chicken manure (~4 tons/ acre)

In 2009 and 2010, in-row mowing was performed with a single sidearm mower on one side of the row, and was independent from middles mowing. The mower attachment is 24 in. wide, and it moves around trees and sprinkler risers by a spring mechanism. About five passes were made each year. In May 2011, the grower switched to use of a weed badger in this orchard, and a single pass was made on all plots except the wood chip and fabric plots. This pass resulted in partial tillage.

From 2009-11, fertilizer application was performed on either side of six adjacent trees in each plot, halfway to the adjacent tree on each end. The manure and feather meal were spread uniformly about 5 ft. on both sides of the row (total of a 10-ft. wide strip). Table 1 shows the fertilizer rates, timings, and rate of N application (based on % total N and % moisture). The values for manure are for the low rate, used for treatment 2; the values for treatments 3, 5, 6, and 7 are double these values.

The fabric, wood chips, and herbicide strip cover a 5-ft. wide strip. The woven landscape fabric used was Lumite Weed Barrier (Shaw Fabrics, Wellington, CO, USA). The fabric was overlapped about 6 in. in the tree row, and fabric pins were placed every 2 ft. along all edges.

The wood chips were uniform in size, consisting of 1- to 3-in. pieces of mixed suburban tree species. They contained 1.0% N, 0.09% P, and 0.34% K, and they had a C:N ratio of about 50:1. In October 2008, they were spread using a wood chip spreader, then manually raked smooth, to a depth of about 6 in. Subsequent applications were made in the spring of 2010 and 2011 at 4 in. depth. This resulted in a rate of about 25 cu. ft./tree, or 224 cu. yds./acre for the Oct. 2008 application, and about 148 cu. yds. each for the 2010 and 2011 applications. Considering that wood chips weigh about 600 lbs./cu. yd., therefore, the application resulted in about 1,344 lbs. N/acre in 2008 and about 890 lbs. N/A in 2010 and 2011, the vast majority of which is tied up in the organic form.

The herbicide used was either GreenMatch at 10% concentration or vinegar (Fleischmann's 300 grain), which was applied with a backpack sprayer at a 20% concentration by mixing two parts vinegar with one part water. Nu-Film P, an organic adjuvant, was added to all herbicide treatments at a 1% v/v concentration. Weeds were also mowed using the sidearm mower as in treatments 1-4.

Evaluations and Measurements

Weed control was visually evaluated periodically to assess treatment effects. Biomass was collected from two randomly placed $0.25m^2$ quadrats per plot, cutting all plants at ground level, separating plants by species, drying and weighing.

Tree growth in each plot was evaluated by measuring trunk cross-sectional area, about 6 in. above soil level, at the end of each season. Midday stem water potential was determined in four of the treatments (3, 5, 6, and 7) before and after a number of irrigations in late spring and summer to determine if in-row weed management practices affect tree water availability. Leaf analysis for N-P-K was done by sampling 80 non-fruiting spur leaves per plot (20/tree) in July, 2009-11.

Soil was sampled at 0-12 in. and 12-24 in. depth in the tree row. Samples were analyzed by the UC Davis Analytical Lab.

Vole and gopher activity were determined by counting the number of holes and mounds in October 2009 and September 2010. Landscape fabric was pulled back for counting, but wood chips were not pulled back because vole holes were clearly visible on the surface of the chips. In 2011, chewing damage by voles was evaluated on the trunk below ground on four trees in each plot.

Prior to harvest, the diameters of 50 fruit in each plot were measured on each of two trees per plot. The middle four trees per plot were harvested (2 picks) and the fruit were weighed.

RESULTS

Weed Control. Key weed species included yellow foxtail (*Setaria pumila)* in the summer and California brome (*Bromus carinatus*) in spring. Weed control in the landscape fabric and wood chip treatments was excellent and significantly better than other treatments at every evaluation in 2009-10 (Fig. 1). In 2011, weed control was still best in these treatments, but not always significantly better (Table 1). The application of herbicides generally resulted in weed control that was better than mowing but not as good as mulch treatments. But in 2011, herbicide applications appeared to do little good, possibly as a result of the pass with a weed badger in April.

Yields and Fruit Quality There were no significant differences in total yield among treatments (data not shown). Average yields for 2009 through 2011 were 29.6, 26.4, and 38.8 tons per acre, respectively. Fruit diameters at harvest showed few differences among treatments; average diameters for 2009, 2010, and 2011 were 2.8, 2.7, and 2.5 in., respectively. No significant differences were found among treatments for fruit weight (avg. = 0.52 and 0.40 lb. for 2010 and 2011, respectively), soluble solids, or fruit pressures.

Trunk Growth. There is a well-known direct correlation between trunk growth and total canopy growth. From 2008 to 2011, there were no significant differences in trunk cross-sectional area among treatments (average 2011 TCSA = 51.3 sq. in.), nor were there differences in growth increase from year to year (data not shown).

Stem water potential. Except for one date, there were no significant differences in stem water potential among treatments (data not shown). The wood chip treatment had significantly lower stem water potential than other treatments in August 2009. Means for this treatment were slightly lower on other dates in 2009 as well, but the differences were not significant. The trees were never stressed in 2009 or 2010; water potentials ranged from 6.2 to 9.2 bars. In 2011, irrigation was delayed and readings were taken at the end of this period; average water potentials were just below 11 bars. Trees wouldn't likely become stressed until about 12 bars.

Leaf Nutrient Content. In both 2009 and 2010, the N content of leaves in mow + no fertilizer was significantly lower than virtually all the high-rate manure treatments and not significantly different from the feather meal or low-rate manure treatments (Table 3a). In 2011, the differences were not significant. Leaf P content tended to be higher in mow + no fertilizer than most high-rate manure treatments, but in 2011 trees in the fabric and wood chip treatments (both with high-rate manure) had significantly higher P content than trees in the feather meal treatment (Table 3b). There were no significant differences between treatments in leaf K content (Table 3c). N, P, and K levels in 2010 and 2011 were lower than in 2009 because only leaf blades were sampled in 2009, whereas blades + petioles were sampled in 2010 and 2012; in the last column of each table, blades alone in one replicate only were sampled and values more closely resemble 2009 content.

Soil samples. In 2010, <u>NO_3-N</u> at 0-12 in. depth was lower in mow + no fertilizer than most other treatments, and in 2011 it was significantly lower in that treatment than in the fabric and wood chip treatments, both of which had a high manure rate (Table 4a). In 2011, the feather meal treatment had significantly more NO_3-N at 12-24 in. depth than under wood chips. <u>Soil P</u> at 0-12 in. was by far the highest under wood chips in 2011, and it tended to be high also at 12-24 in.; soil P also tended to be low under feather meal (Table 4b). <u>Exchangeable K</u> at 0-12 in. under wood chips was significantly higher than either mow + no fertilizer or feather meal in 2010, and in 2011 it was higher under wood chips than all other treatments (Table 4c). No differences between treatments were found in soil levels of total N, Ca, Mg, Na, or CEC (data not shown). <u>Soil pH</u> under feather meal was lower than most other treatments in both 2010 and 2011 (Table 4d). <u>Soil organic matter</u> was highest under wood chips, especially at the 12-24 in. depth (Table 4e).

Voles. In both 2009 and 2010, mulch treatments, especially wood chips, tended to have fewer vole holes than mowed treatments (#1-4) (Table 5). Under the landscape fabric runways were counted as well as holes, since the fabric provided cover and tunnels were not necessary. A rating of vole damage to trees of one each of the weed control treatments (#3, #5-7) found relatively little damage. The fabric mulch treatment had slightly more damage incidence and slightly greater damage severity than other treatments (Table 5). Although some gopher mounds were found in the middles, almost none were found under the tree canopies (data not shown).

Economics. The equipment and materials used for each operation were determined. The time per acre needed for equipment operators and hand labor were calculated, as well as the costs and resource use in gallons of fuel and hours of labor for each alternative.

Total annual weed control costs per acre are substantially different among the various methods (Table 6). Assuming that landscape fabric lasts 8 years, landscape fabric is only somewhat more expensive per acre ($290) than in-row mowing alone ($219), even considering fabric repair costs. An organic herbicide program is far more expensive ($718) because of the cost of GreenMatch and the number of applications required (5) for even marginal weed control. Wood chips were by far the most expensive treatment ($1,040) because of the cost of chips and spreading them, as well as the need to reapply every year. This cost study was based on reapplying the full amount of wood chips (6 in. deep) every other year and half the amount in the alternating years.

Fertilizer costs also varied considerably (Table 6). The use of 2 tons/acre of chicken manure was cheapest ($161). Doubling that rate to 4 tons/acre doubled the cost. Although the cost of feather meal ($1,050/ton, or $525/acre) is more than ten times the cost of chicken manure ($8/yd., with approx. 3.25 yds./ton, or approx. $52/acre for 2 tons), the high cost of delivery and spreading of 2 tons/acre of manure results in a final cost of only about three times that of feather meal for an equivalent amount of nitrogen.

DISCUSSION

The best weed control was obtained with landscape fabric and wood chips. No weeds grew through the overlapped fabric strips, but weeds did grow next to some tree trunks. Weeds grew over the edges of the fabric and deposited seeds onto it. The presence of these edge weeds helped reduce rips from mowing, but some weeds grew from these seeds on the surface of the fabric because of the manure, leaves, and debris that accumulated on it. Roots of these weeds generally did not grow into the soil but remained on the surface of the fabric. Szewczuk and Guderowksa (2006) compared herbicide fallow, pine bark mulch, and black polypropylene fabric mulch on the yield of nectarine grafted on *Prunus mandshurica* in Poland. Only fabric effectively reduced weed growth, but there were no differences in cumulative yield. Pine bark resulted in the greatest trunk cross-sectional area. Fabric mulch also led to very little weed growth in an 8-year study in an apple orchard in the UK (Hipps et al., 2004) and in a mature apple orchard in Arkansas, USA (Rom et al., 2001).

The thick wood chip layer prevented most seedling germination, but perennial weeds (mainly bermudagrass) began to grow in some plots. Because of mulch breakdown over time, it is more effective to apply a thinner layer every year in the early spring than a thick layer every two years, assuming that any weeds are mowed before application. Although no treatments were under water stress at any point in 2009, trees with wood chips had improved water status (less negative water potential) compared to the other treatments measured just before harvest in 2009. But there were no differences in 2010 or 2011, and during a water stress period in 2011 trees at one end of the field were more stressed than the other, regardless of the weed control treatments. Granatstein and Mullinix (2008) found that plots mulched with 6 in. thick wood chips in tree rows of a young Gala apple orchard consistently had 15-20% higher soil moisture at the end of each irrigation cycle than the bare ground plots. The water content of soil in an apple orchard in Belgium decreased quickly under clean cultivation and under grass after the irrigation, decreased more slowly where farmyard manure, pine bark mulch and straw were used in the tree rows, and remained nearly constant under plastic fabric mulch (Lakatos and Buban, 2000).

All fertilizer treatments tended to increase NO3-N at least marginally at both 0-12 in. and 12-24 in. soil depth, with feather meal perhaps highest at the greater depth, and yet there were no differences in leaf N content. Wood chips were found to contain 1.0% N, 0.09% P, and 0.34% K, with a C:N ratio of 51:1. Tahboub and Lindemann (2007) found that pecan wood chips had an average of 0.45% N, 0.03% P, and 0.28% K, with a C:N ratio of 143:1. The wood chips used in the current study were mixed species and likely contained more leaves and therefore more N and a lower C:N ratio. The total amount of wood chips applied was about 520 yds/acre over three years. Assuming that wood chips weigh about 600 lbs./cu. yd., the total amount of nutrients applied per acre during this period was about 3,120 lbs. of N, 280 lbs. of P, and 1,060 lbs. of K. Although the N content of the wood chips was high, the high C:N ratio likely led to net N immobilization. As a result, the soil NO3-N content was no higher under wood chips, but the P and K levels were higher. This contrasts with Faber et al. (2003), who maintained 6 in. of wood chips in an avocado orchard for 4 years and found significantly greater N, P, K, and Zn at 4 in. soil depth. Continuing the current study for a fourth year could have resulted in higher N levels under wood chips. Wood chips did not affect soil pH, and as might be expected, soil organic matter content increased below the wood chip layer at both the 0-12 in. and 12-24 in. depths.

Total costs among weed control treatments varied substantially. Wood chips are by far the most expensive and, although they largely controlled most weeds, they have not provided a benefit in tree growth or yield. If landscape fabric lasts eight years, per-year costs will be similar to in-row mowing, and trunk damage by the sidearm mower will be eliminated. A 2004-2006 Washington (USA) study showed that the total cost of applying a 1.5-m wide, 15-cm thick layer of wood chips was $2,283/ha (Wiman et al., 2007). In that study, which compared two in-row tillage implements, in-row mowing, and wood chip mulch, wood chips provided the best weed control in all 3 years, although it needed reapplication in year 3. This treatment also produced the greatest tree growth and fruit size. Organic herbicides are expensive and not very effective against summer weeds, particularly yellow foxtail.

Feather meal is one of the most concentrated organic fertilizers, so application costs are far lower than manure, but the total cost is still three times higher than chicken manure. However, in recent years chicken manure is often not available, making feather meal the only practical alternative.

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Fig. 1. Percent weed control of mowing alone (mean of 4 mowing treatments) vs. other methods, 2009-10.

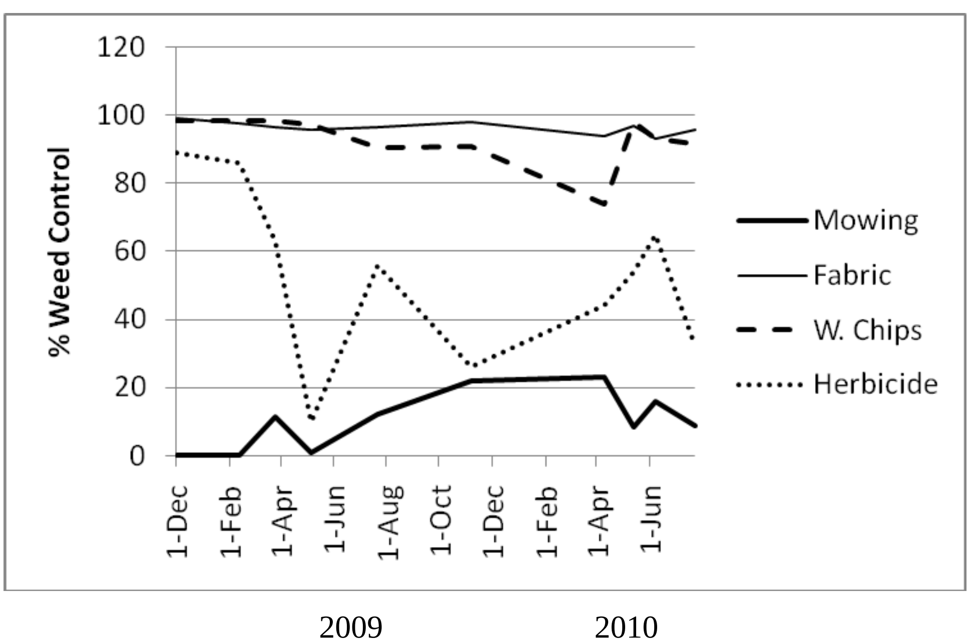

Table 1. Rates and timings of fertilizers and rate of N application.

	Manure[1] (Low Rate)[1]			Feather Meal		
	Applied Rate (tons/acre)	Total N (%)	Total N (lbs./acre)	Applied Rate (tons/acre)	Total N (%)	Total N (lbs./acre)
10/14/08	2.0	3.2	128	0.50	11.0	103
9/30/09	2.0	2.6	104	0.50	7.7	74
4/14/10	1.0	2.9	58	0.38	12.0	88
9/29/10	2.2	2.3	101	0.90[2]	12.0	216
4/2/11	1.0	2.1	92	0.25	12.0	30
Total applied N			483			511

[1]High rate treatment is double the low rate treatment.
[2]An incorrect lab analysis led to double the application rate; the lab admitted its computational mistake after application.

Table 2. Percent weed cover, 2011.

Treatment	Jan.	Apr.	May	June	Sept.
1. Mow, no fertilizer	35 a[1]	42 ab	21 a	27 a	37 ab
2. Mow, manure low	46 a	61 a	26 a	33 a	60 a
3. Mow, manure high	30 a	37 ab	14 a	19 a	45 a
4. Mow, feather	38 a	47 a	20 a	33 a	53 a
5. Fabric, manure high	13 a	15 b	8 a	8 a	17 b
6. Chips, manure high	8 b	11 b	10 a	9 a	12 b
7. Herb., manure high	35 a	42 ab	18 a	19 a	51 a

[1]Means separation within columns at 5% level (LSD).

Table 3 a-c. Leaf nutrient analyses, leaves sampled July 2009-11. Because blades only were sampled in 2009, blades from one replicate of each treatment were also sampled in 2011 for comparison and were about 0.2% higher than blades + petioles.

3a. Leaf total nitrogen (%)

	2009	2010	2011	2011
Treatment	Blades Only	Blades + Petioles	Blades + Petioles	Blades Only
1. Mow, no fertilizer	2.20 c[1]	2.08 c	2.10 a	2.36
2. Mow, manure low	2.23 bc	2.16 bc	2.14 a	2.31
3. Mow, manure high	2.29 abc	2.21 ab	2.18 a	2.43
4. Mow, feather	2.23 bc	2.15 bc	2.12 a	2.31
5. Fabric, manure high	2.41 a	2.26 a	2.12 a	2.36
6. Chips, manure high	2.38 ab	2.20 ab	2.14 a	2.28
7. Herb., manure high	2.39 ab	2.20 ab	2.18 a	2.43
P Value	*0.01*	*0.001*	*0.12*	--[2]

[1]Means separation within columns at 5% level, Tukey HSD test. [2]See Table 3 heading.

3b. Leaf phosphorus (%)

Treatment	2009 Blades Only	2010 Blades + Petioles	2011 Blades + Petioles	2011 Blades Only
1. Mow, no fertilizer	0.200 a[1]	0.169 a	0.158 ab	0.154
2. Mow, manure low	0.182 a	0.161 ab	0.158 ab	0.161
3. Mow, manure high	0.176 a	0.148 bc	0.153 ab	0.172
4. Mow, feather	0.192 a	0.146 bc	0.144 b	0.174
5. Fabric, manure high	0.158 a	0.142 c	0.164 a	0.169
6. Chips, manure high	0.182 a	0.158 abc	0.171 a	0.190
7. Herb., manure high	0.172 a	0.148 bc	0.157 ab	0.168
P Value	*0.06*	*0.001*	*0.005*	--[2]

[1]Means separation within columns at 5% level, Tukey HSD test. [2]See Table 3 heading.

3c. Leaf potassium (%)

Treatment	2009 Blades Only	2010 Blades + Petioles	2011 Blades + Petioles	2011 Blades Only
1. Mow, no fertilizer	1.01[1]	0.78	0.76	0.73
2. Mow, manure low	0.91	0.74	0.70	0.93
3. Mow, manure high	0.91	0.71	0.75	0.82
4. Mow, feather	0.99	0.69	0.66	0.78
5. Fabric, manure high	0.93	0.66	0.73	0.75
6. Chips, manure high	1.03	0.74	0.78	0.95
7. Herb., manure high	0.91	0.68	0.70	0.80
P Value	*0.86*	*0.40*	*0.33*	--[2]

[1]No significant differences, 5% level. [2]See Table 3 heading.

Table 4 a-e. Soil analyses.

4a. Soil nitrate-nitrogen (ppm)

	0-12 in.			12-24 in.	
Treatment	2009	2010	2011	2009	2011
1. Mow, no fertilizer	6.6 a[1]	7.9 b	9.6 b	4.0 a	6.7 b
2. Mow, manure low	7.2 a	10.7 ab	15.1 ab	4.9 a	10.9 ab
3. Mow, manure high	10.5 a	12.4 ab	16.0 ab	8.0 a	13.1 ab
4. Mow, feather	7.7 a	17.2 a	16.7 ab	5.3 a	18.6 a
5. Fabric, manure high	11.7 a	15.3 a	18.3 a	8.3 a	10.9 ab
6. Chips, manure high	8.1 a	13.9 ab	18.6 a	5.8 a	9.7 b
7. Herb., manure high	10.2 a	17.2 a	16.2 ab	9.0 a	13.0 ab
P Value	*0.08*	*0.002*	*0.03*	*0.03*	*0.01*

[1]Means separation within columns at 5% level, Tukey HSD test.

4b. Soil phosphate-phosphorus (Olsen-P) (ppm), Sept. 2011 only

Treatment	0-12 in.	12-24 in.
1. Mow, no fertilizer	51.5 d[1]	38.3 b
2. Mow, manure low	73.0 bc	41.8 b
3. Mow, manure high	85.8 b	51.7 ab
4. Mow, feather	57.9 cd	36.6 b
5. Fabric, manure high	71.6 bc	41.8 b
6. Chips, manure high	101.3 a	57.5 a
7. Herb., manure high	84.0 b	49.8 ab
P Value	*0.001*	*0.002*

[1]Means separation within columns at 5% level, Tukey HSD test.

4c. Soil exchangeable potassium (ppm)

	0-12 in.			12-24 in.	
Treatment	2009	2010	2011	2009	2011
1. Mow, no fertilizer	315 a[1]	332 bc	387 b	150 a	175 a
2. Mow, manure low	391 a	381 abc	439 b	163 a	176 a
3. Mow, manure high	394 a	364 abc	447 b	154 a	196 a
4. Mow, feather	363 a	309 c	392 b	143 a	166 a
5. Fabric, manure high	378 a	360 abc	389 b	151 a	178 a
6. Chips, manure high	367 a	468 a	594 a	146 a	192 a
7. Herb., manure high	391 a	428 ab	466 b	149 a	183 a
P Value	*0.11*	*0.03*	*0.001*	*0.65*	*0.44*

[1]Means separation within columns at 5% level, Tukey HSD test.

4d. Soil pH, 0-12 in. depth

Treatment	2009	2010	2011
1. Mow, no fertilizer	6.78 abc[1]	6.86 ab	6.74 a
2. Mow, manure low	6.78 abc	6.80 ab	6.70 a
3. Mow, manure high	6.74 abc	6.80 ab	6.66 ab
4. Mow, feather	6.76 abc	6.62 c	6.38 d
5. Fabric, manure high	6.64 c	6.74 abc	6.51 cd
6. Chips, manure high	6.90 a	6.88 a	6.69 ab
7. Herb., manure high	6.84 ab	6.70 abc	6.59 bc
P Value	*0.01*	*0.001*	*0.001*

[1]Means separation within columns at 5% level, Tukey HSD test.

4e. Soil organic matter (%)

Treatment	2010 0-12 in.	2011 0-12 in.	2011 12-24 in.
1. Mow, no fertilizer	3.88 a[1]	3.79 b	3.38 b
2. Mow, manure low	4.29 a	4.19 ab	3.22 b
3. Mow, manure high	4.03 a	4.35 ab	3.36 b
4. Mow, feather	4.11 a	4.24 ab	3.28 b
5. Fabric, manure high	4.25 a	3.94 b	3.14 b
6. Chips, manure high	4.49 a	5.05 a	4.16 a
7. Herb., manure high	4.41 a	4.12 ab	3.29 b
P Value	*0.18*	*0.01*	*0.001*

[1]Means separation within columns at 5% level, Tukey HSD test.

Table 5. Vole holes and vole damage.

	2009 No. of Vole Holes in Soil[1]	2010 No. of Vole Holes in Soil[1]	2011 % of Trees with Damage[2]	2011 Avg. Damage Rating[3]
1. Mow, no fertilizer	35.0 a[4]	27.8 ab	25.0	0.30 a
2. Mow, manure low	30.0 ab	23.0 abc	--	--
3. Mow, manure high	31.8 ab	32.4 a	12.5	0.20 a
4. Mow, feather	34.8 a	16.8 abc	--	--
5. Fabric, manure high	12.2 bc	9.2 bc	37.5	0.55 a
6. Chips, manure high	6.6 c	4.2 c	12.5	0.10 a
7. Herb., manure high	15.8 abc	12.4 abc	18.8	0.15 a
P Value	*0.01*	*0.02*	--	*0.22*

[1]No. of holes per 6-tree plot (one side of tree row only). [2]Damage on trunks 0-8 in. below soil surface.
[3]Percent of trunk damage rating (0 = no damage, 1 = 1-20%, 2 = 21-40%, 3 = [4]1-60%, 4 = 61-80%, 5 = 80-100%).
[4]Means separation within columns at 5% level (Tukey HSD test).

Table 6. Costs of weed control and fertilizer practices per acre.

	Total Operating Costs	Cash & Non-Cash Overhead Costs	Total Costs
Weed Control			
1. Mowing	176	43	219
2. Landscape fabric	56	234	290
3. Wood chips	240	800	1,040
4. Herbicide	699	19	718
Fertilizer			
1. Manure – low rate	142	19	161
2. Manure – high rate	284	38	322
3. Feather meal	580	6	586