Sustainability Trade-Offs in Organic Orchard Floor Management

D. Granatstein, M. Wiman and E. Kirby
Center for Sustaining Agriculture
and Natural Resources
Washington State University Tree Fruit
Research and Extension Center
1100 N. Western Ave.
Wenatchee, WA 98801
USA

K. Mullinix
Institute for Sustainable Horticulture
Kwantlen Polytechnic University
Surrey, BC
Canada

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Abstract

Sustainability is a primary goal of organic farming systems, particularly with regard to environmental factors. Modern orchard systems in general benefit from the perennial nature of the crop and the reduced impacts to soil and water with the absence of tillage. In the Pacific Northwest region of the USA, most pome and stone fruit orchards utilize herbicides to manage weeds in the tree row, and a perennial grass cover in the drive alley to reduce dust and provide a stable surface for machinery traffic. Organic orchards in the region do not have an acceptable herbicide option, and thus typically rely on weed control through soil tillage, which can compromise soil quality. Tillage was compared with wood chip mulch and an undisturbed control in a 3-yr trial. Tillage did not lead to consistent soil quality decline; however, it did lead to poorer tree performance relative to the control, while wood chip mulch improved tree performance. Both options provided good weed control. Related trials with living mulch in the tree row showed soil quality benefits and meaningful N contribution, but had severe competition with trees and elevated vole populations. Results to date suggest that an integration of practices will be needed to optimize sustainability.

INTRODUCTION

The concept of sustainability is built on the three legs of economics, ecology, and equity. In agricultural systems, this implies that a farm must be managed to simultaneously be economically viable, environmentally sound, and socially acceptable to the extent possible (Granatstein and Kupferman, 2008). The three legs interact: an unprofitable farm cannot address environmental or social sustainability; environmental improvements can lead to greater profitability; investments in workers can improve economic and environmental performance. Historically, organic agriculture has focused on the environmental component of sustainability, eschewing synthetic compounds for their potential negative ecological consequences and emphasizing soil organic matter, nutrient cycles and biodiversity as functional components to achieve productivity and profitability while protecting the environment. However, not all accepted organic practices meet an environmental sustainability test. Copper fungicides are known to elevate Cu levels in soil and possibly inhibit soil organisms (Viti et al., 2008; Zwieten et al., 2004). Tillage, the common alternative to herbicides for weed control, can easily degrade soil quality (Fiscus and Neher, 2002; Six et al., 1998). Sulfur, a widely used foliar fungicide, disrupts certain natural enemies and their potential biological pest control (James et al., 2002).

All orchard floor management choices have sustainability trade-offs. For example, tillage provides effective weed control and reduces rodent pest habitat, but it oxidizes soil organic matter, and can damage roots, trunks, and irrigation lines. Tillage also requires substantial fossil fuel use and contributes to atmospheric CO₂. In contrast, living mulches add biodiversity, improve soil quality, and if leguminous, provide an internal source of nitrogen. However, they can severely compete with trees, provide excellent rodent habitat.
(Merwin et al., 1999), and vary in their persistence and their ability to suppress weeds (Granatstein and Mullinix, 2008).

Increasingly, producers are being asked to address sustainability. Organic tree fruit production in Washington State, USA, relies on irrigation water from mountain snowpack, and the effect of climate change on water supply due to reduced snowpack and early rapid snowmelt is anticipated to impact growers (Bauman et al., 2006). Therefore, orchard floor management strategies that provide ecosystem services such as water conservation (e.g., through mulching), fossil fuel conservation, and greenhouse gas abatement will become increasingly important for long-term sustainability. The experimental work reported here is part of an ongoing effort to identify orchard floor management practices and their combination into systems that meet organic certification standards and enhance sustainability.

MATERIALS AND METHODS

The trial was conducted at the Wenatchee Valley College Teaching and Demonstration Orchard, East Wenatchee, WA, USA, on a Pogue fine sandy loam (Aridic Haploxeroll), averaging 1 to 1.5% organic matter and pH 6.1 to 7.3; average annual precipitation is 215 mm. All plots were irrigated with micro-jet sprinklers and received the same standard pest control and compost fertilization.

The trial was established in April 2004 in an 8-yr-old block of ‘Gala’/M.26 apple (Malus × domestica) in transition to organic certification. Trees were planted on a 1.06 m x 3.96 m spacing, with grass (perennial rye [Lolium perenne]/tall fescue [Schedonorus phoenix (Scop.) Holub] mix) in the drive alleys. Treatments included control (weeds mowed 3–4 times per season with weed-eater to prevent seed formation); wood chip mulch (applied 15 cm thick over the approximately 1.5 m wide tree row in April 2004 and April 2006); and tillage of the tree row (3 times per season in 2004 and 2005, 2 times in 2006, with a Wonder Weeder®, a ground-driven rolling cultivator with a spring blade that works in between the tree trunks; [Harris Mfg., Burbank, WA, USA]). Plot size was 10 trees (10.66–12.99 m long x 3.96 m wide). The experimental design was a randomized complete block with 5 replicates.

Weed percent cover was visually estimated (0–100%) using three subsamples of a 0.25 m² ring randomly tossed in the tree row. Trunk cross-sectional area was measured at the end of year 2 and 3 at 20 cm above the graft union. Soil active carbon was measured for September 2006 samples (0–5 cm depth in the tree row), using a 21-day aerobic incubation in sealed centrifuge tubes at ambient temperature in the dark. CO₂ was extracted with a syringe on days 3, 7, 12, 17, and 21, and concentration was determined by gas chromatography (GC-17A, Shimadzu, Kyoto, Japan). Water infiltration was measured with a Mini-Disk infiltrometer (Decagon Devices Inc., Pullman, WA, USA) set at 0.5 and 2.0 cm tension for two consecutive runs, with three subsamples per plot in the tree row 30–50 cm to the side of the trunks. Soil resistance was measured with a Rimik CP20 cone penetrometer (Agridry RIMIK Pty. Ltd., Toowoomba, Queensland, Australia) to 425 mm depth (if the probe was able to penetrate that far), with readings every 15 mm, using 9 measurements per plot in the tree row about 30–50 cm to the side of the trunks.

Statistical analyses were conducted with SAS (version 8) using analysis of variance, and means were compared with Fisher’s Least Significant Difference (p<0.05) (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Two major goals for orchard floor management are eliminating weed competition with the trees and minimizing habitat for potentially destructive rodents (e.g., Microtus spp.). Weed control contrasted greatly among treatments. Wood chip mulch consistently had the lowest percent weed cover (generally below 20%), compared to 20–60% for tillage and 40–90% for control (mow) (Fig. 1). Each tillage operation induced a new flush of weeds, primarily annual grasses, and the soil seed bank did not appear to decrease over the three years of the study. Increasing tillage frequency did not lead to consistent weed
biomass reduction relative to the control (data not shown). Rodent presence was monitored in a nearby new experimental planting, and there were no significant differences among wood chip mulch, tillage, and bare ground control for the late fall and early spring sample dates (Wiman et al., 2009). However, living mulch plots in that trial showed a 10-fold increase in rodent presence, but little tree damage occurred over that particular winter season.

Orchard floor management did influence tree growth. Trunk cross-sectional area was 40.1, 44.2, and 47.5 cm² for tillage, control, and wood chip, respectively, with significant differences ($p<0.05$) among treatments. Canopy volume followed a similar pattern, with wood chip and tillage being significantly different ($p<0.05$). Fruit yield showed the same trend, although differences were not significant. However, wood chip mulch led to a significantly greater ($p<0.05$) percent of the fruit in size class 80–88 count (202–249 g) which is the economically optimum size. This size class had the highest market price, and thus wood chip mulch led to greater predicted gross returns.

Soil quality maintenance is required by organic standards, and water scarcity is an increasing sustainability issue in semi-arid fruit producing regions. Water infiltration can be rapidly impacted by soil management, and thus serves as an indicator of soil quality changes. Infiltration measurements were taken in years 2 and 3 at two tensions to separately monitor macropore (0.5 cm tension) and smaller pore (2 cm tension) effects. The undisturbed soil in the control had the highest infiltration in both years, but there was no difference between tilled and wood chip mulch (Table 1). Soil penetrometer measurements, another indicator of soil quality, showed wood chips with the lowest resistance at 10–20 cm depth, while tillage showed the highest, and increasing, resistance below 25 cm depth in Year 1. For Year 2, control plots had the lowest resistance across depth, wood chips the highest, and tillage was in between (data not shown). While soil moisture was not monitored in this trial, measurable water conservation from orchard floor mulching was achieved in a previous trial in the same orchard (Granatstein and Mullinix, 2008). For volumetric water content (0–20 cm depth), in-row living mulch (white clover [*Trifolium repens*]) always had significantly greater ($p<0.05$) soil moisture than bare ground control. Living mulch was equal to or greater than wood chip mulch, and wood chip mulch was mostly significantly greater than control (Fig. 2). A similar pattern was observed in the previous year in the same trial with unreplicated summer-long measurements.

There were no treatment differences in soil active carbon at the end of the three years (Fig. 3). The lack of a clear soil quality benefit from wood chip mulch was surprising, given the large carbon input and the proliferation of feeder roots and fungal hyphae in the mulch layer that were observed. However, soil samples were taken from below the mulch layer. In contrast, significant changes in soil total C and N were detected in a subsequent trial after two years, with increases for the in-row living mulches, and decreases for tillage and wood chip mulch, relative to the bare ground control (Table 2) (Hoagland, 2007).

Another sustainability aspect that needs to be considered is economics. Based on treatments from this trial, results from other trials (Hogue et al., 2003), and grower experience, estimated costs for several orchard floor management practices were compiled and are presented in Table 3. Tillage (Wonder Weeder; 20 times faster than another commonly used cultivator) and flaming (propane) were similar in cost, and also similar in cost to a conventional contact herbicide program. Wood chip mulch was considerably more expensive, but in this trial, the value added from the resulting increase in optimal fruit size more than covered the annual cost of the mulch application. Weed fabrics have exhibited mixed results. Neilsen et al. (2003) found tree performance with weed fabric to be similar to an herbicide control and not as good as several organic mulch treatments used at Summerland, British Columbia, Canada, an area with intense summer heat. In addition, some soil quality parameters were lowest under the fabric, perhaps due to elevated soil temperatures during the heat of summer (Forge et al., 2003). In contrast, a study at Hood River, Oregon, USA, showed significant increases in sweet cherry tree
growth and fruit yield with weed fabric that more than paid for the added expense of the fabric while also providing excellent weed control (Yin et al., 2007). Thus, choice of orchard floor management should account for the growing environment and orchard age to optimize sustainability outcomes.

CONCLUSIONS

No orchard floor management practice in this trial or related trials produced an ideal combination of tree health, weed control, soil quality, and economic return. For tree growth, wood chip mulch > control > tillage, while leaf N ranked living mulch = tillage > control > wood chip. The wood chip mulch is apparently delivering a non-nitrogen-related benefit. The trend for fruit yield and size, and thus gross returns, in this trial was wood chip mulch > control > tillage. Soil quality ranked living mulch > control > wood chip mulch > tillage. Living mulches show promise for soil quality improvement and are attractive since they can be produced with renewable resources and little external input once established. Living mulches tested in related trials provided good in-row weed control and contained enough N in above-ground biomass to meet annual tree N needs. But competition with the trees was generally unacceptable, as were elevated vole populations. Strategies to manage this competition in organic orchards without losing the other benefits are needed.

ACKNOWLEDGEMENTS

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Literature Cited


Tables

Table 1. Water infiltration in tree row in years 2005 and 2006.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T0.5</td>
<td>T2.0</td>
</tr>
<tr>
<td>Control (mow)</td>
<td>2.3a</td>
<td>1.0</td>
</tr>
<tr>
<td>Wood chip</td>
<td>0.9b</td>
<td>0.7</td>
</tr>
<tr>
<td>Tillage</td>
<td>1.3b</td>
<td>1.0</td>
</tr>
</tbody>
</table>

p= 0.0088 0.1400 0.0052 0.0083

T0.5 tension at 0.5 cm; T2.0 tension at 2.0 cm.
Means with the same letter in a column are not significantly different at p<0.05 using FLSD.

Table 2. Impact of orchard floor management on soil C and N (0–10 cm depth). Adapted from L. Hoagland, 2007.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total C (%)</th>
<th>Total N (mg kg⁻¹ soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfertilized control*</td>
<td>1.19 cde</td>
<td>920 d</td>
</tr>
<tr>
<td>Control, bare ground</td>
<td>1.25 bcd</td>
<td>1100 bc</td>
</tr>
<tr>
<td>Till</td>
<td>1.05 f</td>
<td>800 ef</td>
</tr>
<tr>
<td>Living mulch, legume</td>
<td>1.43 a</td>
<td>1240 a</td>
</tr>
<tr>
<td>Living mulch, non-legume</td>
<td>1.46 a</td>
<td>1210 ab</td>
</tr>
<tr>
<td>Wood chip mulch</td>
<td>1.16 def</td>
<td>920 d</td>
</tr>
</tbody>
</table>

*bare ground, no disturbance, no compost; all other treatments received compost.
Means with the same letter in a column are not significantly different at p<0.05 using FLSD.
Table 3. Alternative weed control costs. Adapted from Hogue et al. (2003).

<table>
<thead>
<tr>
<th>Method</th>
<th>Rate (ha⁻¹)</th>
<th>Frequency</th>
<th>Cost ha⁻¹ yr⁻¹ ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage¹</td>
<td>0.62 h</td>
<td>3 per yr</td>
<td>296</td>
</tr>
<tr>
<td>Wood chip mulch</td>
<td>100 m³</td>
<td>1 per 3 yr</td>
<td>494 296</td>
</tr>
<tr>
<td>Alfalfa hay mulch</td>
<td>19.1 Mg</td>
<td>1 per 2 yr</td>
<td>788 370</td>
</tr>
<tr>
<td>Spray on paper</td>
<td>7.6 Mg</td>
<td>1 per 1.5 yr</td>
<td>578 370</td>
</tr>
<tr>
<td>Flaming</td>
<td>54 kg</td>
<td>3 per year</td>
<td>89 222</td>
</tr>
<tr>
<td>Weed fabric</td>
<td>1.5 m x 1143 m</td>
<td>1 per 6 yr</td>
<td>706 222</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>1.24 L</td>
<td>4 per yr</td>
<td>59 126 832</td>
</tr>
</tbody>
</table>

¹Tillage with Wonder Weeder at 122 m min⁻¹ per side of tree row.

Figures

Fig. 2. Mid-summer 2001 trend in volumetric soil moisture content (0–20 cm depth; mean of 5 replicates) in a 9-year old Red Delicious/M.26 block with three different in-row management treatments. Measurements taken with Hydrosense TDR meter, Decagon Devices, Pullman, WA, USA. Adapted from Granatstein and Mullinix (2008).

Fig. 3. Effect of orchard floor management on soil active carbon (daily rate, 0–5 cm depth).