NITROGEN CYCLING AND PARTITIONING UNDER ALTERNATIVE ORGANIC ORCHARD FLOOR MANAGEMENT STRATEGIES

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ABSTRACT

Organic orchard systems are a significant and growing component of Washington State agriculture, yet sustainable methods of nitrogen (N) fertility and weed management remain a challenge. Nutrient supply is dependent on decomposition and mineralization of organic matter, yet intensive cultivation commonly used to control weeds can disrupt biological processes and cause loss of organic matter. To address the often-competing goals of organic fertility and weed control, a number of alternative orchard floor management strategies were implemented and evaluated for their impact on N cycling, soil quality, and tree health in a newly established orchard. The standard practice of weed control using extensive tillage resulted in trees with good growth and acceptable levels of leaf N and most other essential nutrients, conversely, soil quality was in decline and may negatively impact long-term nutrient dynamics. Maintenance of a living cover understory resulted in greater N retention and availability, and rapid soil quality improvement, yet it severely competed with young trees, resulting in reduced tree growth. Covering the understory with wood chip mulch enhanced soil moisture and resulted in adequate tree growth, but it also facilitated N loss and correspondingly resulted in low tree leaf N. Application of a clove oil herbicide resulted in lower leaf N and tree growth in comparison to cultivated treatments and did not positively impact soil quality parameters. In contrast, Brassicaceae seedmeal (BSM) applications enhanced N availability and soil faunal biomass, yet leaf N did not reach acceptable levels and many of the other essential nutrients were lowest in this treatment. Tree leaf chlorosis was observed following an early season BSM application and may have been the result of reduced soil iron availability. None of the treatments applied produced an ideal combination of weed control, maximum tree growth, adequate leaf nutrients, and improved soil quality. Rather, soil quality improvements tended to compete with tree performance.

INTRODUCTION

Fueled by consumer demand and innovative research, organic tree fruit production is thriving, yet sustainable methods of nitrogen (N) fertility and weed management remain a challenge. Extensive research has determined ideal timing and application rates for N fertilizer, but the majority of these data were generated using synthetic fertilizers that contain N in readily available plant accessible forms. In contrast, organic systems generally rely on complex organic materials such as composted animal manures to supply N, but only a fraction of the nutrients are in immediately available forms with the remainder released slowly as a result of microbial driven processes. In addition, these amendments come at a high cost, and excess application may result in salt damage, N loss and environmental degradation (Stork and Jerie, 2003). Systems are needed that will help reduce N fertility costs, mitigate loss, and enhance availability at times corresponding with critical tree uptake periods.

In the absence of reliable herbicides certified for use in organic systems, orchard managers often control weeds with intensive cultivation; a practice that can degrade soil structure, negatively impact functional soil faunal communities and accelerate nutrient cycling and organic matter loss. In contrast, practices that reduce disturbance may help to ameliorate negative impact on soil quality and enhance N availability. For example, wood chip mulch may contribute recalcitrant carbon compounds that improve long-term soil nutrient and water-holding capacity, however, they may also result in short-term N immobilization given their high C:N ratio (Larsson et al., 1997). Alternatively, maintenance of a vegetative cover or “living mulch” can reduce nutrient loss by acting as a ‘catch crop’, immobilizing and retaining available soil N, and/or contribute additional N via residue decomposition if leguminous (Marsh et al., 1996; Sanchez et al., 2003; and Stork and Jerrie, 2003). In addition, root exudates and decaying residues from cover crops contribute labile carbon compounds that stimulate microbial activity responsible for enhanced nutrient retention and cycling (Wardle et al., 2001), and disease control (Forge et al., 2001). However, living cover crops also compete with trees for nutrients and water, reducing tree growth and yield, particularly in young trees or when N demanding grasses predominant (Marsh et al., 1996; and Sanchez et al., 2003). Organic herbicides like those derived from clove oil will reduce soil disturbance, but their effect on N cycling and soil quality is unknown. Application of Brassicacea seedmeal, a byproduct of bio-fuel production, could reduce soil disturbance and contribute multiple benefits, potentially serving as a supplemental N fertilizer, as well as providing weed and disease control through complex microbial interactions (Mazzola et al., 2006), but its effect on N availability and tree health is unclear.

To address the needs of Washington state orchardists for sustainable methods of N fertility and reduced disturbance weed control, the impact of alternative orchard floor management strategies on N cycling, soil quality and tree health was evaluated. Varying levels of amendment were utilized to determine N-use efficiency in these alternative systems. Identifying short-term treatment differences in fertility studies conducted on mature trees is difficult due to ample nutrient reserves and inherent soil fertility. Therefore, these studies were conducted in a newly established orchard, where young trees are heavily impacted by available soil N, and would more likely reflect impacts of orchard floor management practices.

METHODS

The orchard was established in spring 2005 at the Wenatchee Valley College organic orchard site in east Wenatchee, WA, using Piñata on M7 rootstock. A number of alternative orchard floor management strategies were overlain with different fertility rates (Table 1). The living cover mulch crops were either planted on the entire plot or limited to a strip within the tree row in a “sandwich” system.

Table 1. Treatment Summary

Code	Weed Control	Soil Disturbance	Compost Fertilizer
CON	Control	Low	0X
BHE	Brassica Seedmeal Herbicide	Medium	0.5X
CHE	Clove Oil Herbicide	Low	1X
WC	Wood Chip Mulch	Low	1X, 1.5X
LML	Living Mulch Legume	Low	0.5X, 1.5X
LMNL	Living Mulch Non-Legume	Low	0.5X, 1X, 1.5X
CLT	Cultivated	High	0.5X, 1X, 1.5X
SWL	Sandwich Legume	Medium	1X
SWNL	Sandwich Non-Legume	Medium	1X

In 2005, pelleted chicken manure compost (4% N) was broadcast at a rate of 90 lbs total N/ac (1X), and mechanically incorporated prior to establishment of orchard floor treatments. In mid-July bloodmeal (12% N) was injected under each tree, at a rate 32 lbs total N/ac (1X), and supplemental foliar applications of fish emulsion and kelp were applied to all trees at a rate of 2.4 lbs total N/ac. In 2006, N availability of from amendments were pre-determined and the 1X rate was adjusted upward accordingly. As a result, equal amounts of two different chicken manure composts (3.5% and 4% N), with available N estimated at 51 and 28% respectively, were spread around the base of each tree in four equal, split-applications (April, early and mid-May, June) for a total of approximately 90 lbs available N/acre. Brassicacea seedmeal (*Sinapis alba*) (6.84% N) was broadcast over BHE plots at a rate of 0.5 tons/ac using one application in 2005, and 1.5 tons/ac in three equal split-applications in 2006. In 2006, compost treated with ^{15}N-enriched fertilizer was used on selected trees in the 1X CLT, WC, and LML treatments to allow measurement of N partitioning.

Chemical and biological indicator analyses were carried out using pooled soil cores collected each spring (including baseline), summer and fall of 2005 and 2006. Analyses included: total available and potentially available N, total C and N, active (particulate organic matter fraction) C and N, mineralizable C, microbial activity (dehydrogenase) and nematode abundance and diversity. Apple tree leaves were selectively sampled in late July and analyzed for N as well as 12 other mineral elements. Tree cross-sectional area (TCSA) was measured shortly after tree establishment, and again each fall following soil collection.

RESULTS AND DISCUSSION

The standard cultivation practice for weed control resulted in sufficient available soil N (Figure 1) and successfully eliminated weed competition, which produced adequate tree growth (Figure 2) and acceptable levels of leaf N for young non-bearing trees, and most other essential nutrients (Table 2). There were no significant differences between the varying fertility levels within this treatment, indicating that in the short-term, meeting tree N needs and maximizing nutrient-use efficiency could be achieved at the low N rate. In contrast, cultivation ranked among the lowest in terms of soil available N (Figure 1), total and labile C and N (Table 3), and soil faunal abundance and activity (data not shown), indicating a reduction in soil quality that may have negative consequences on nutrient cycling and tree health in the long-term.

None of the reduced disturbance, alternative treatments provided a combination of good growth and acceptable levels of leaf N. Although the 1X legume and non-legume treatments had the highest level of leaf N and were well within acceptable limits (Table 2), all living mulch treatments exhibited less tree growth (Figure 2). Sandwich treatments with reduced living cover resulted in greater tree growth, but leaf N levels did not reach desirable levels (Table 2).

Analysis of ^{15}N data confirmed immoblization of compost N in living cover crops, yet this cycles back to the system after cutting, resulting in sufficient pools of available soil N (data not shown). Living cover crops successfully retained available N lost from other treatments during winter leaching and as a result, had greater available N in early spring and throughout the growing season (Figure 1). Given that available soil N was high under living covers, and given the insignificant response to higher rates of compost amendment, the reduced tree growth observed with living covers may have resulted from moisture competition. Another factor may be the late-season injection of soluble N fertilizer applied in autumn 2005 to all trees. It was visually apparent that living cover mulch crops recovered a substantial portion of this additional N, whereas in non-living cover treatment this N was likely taken up by the trees and contributed to their rapid growth in spring 2006. Although tree growth was reduced in living mulch treatments, they ranked highest in terms of all soil quality indicators, which may lead to increased nutrient-use efficiency and potentially healthier trees over time.

Wood chip mulch resulted in good tree growth (Figure 2), but tree leaf N was well below desirable levels (Table 2). Increasing compost amendment with wood chip treatment led to higher leaf nutrient levels, but not enough to meet levels suggested by previous research as desirable for young non-bearing trees. While ^{15}N analyses indicate initial immobilization of N in the wood chip residue (data not shown), available N slowly cycles into the soil and is subsequently lost from the system as confirmed by analyses of available, labile and total N in the active soil fraction (Figure 1 and Table 3). This treatment resulted in abundant soil moisture availability and enhanced tree growth but may have contributed to N loss from the system through denitrification or leaching mechanisms. In addition, despite substantial inputs of total C from wood chip mulch, this treatment ranked among the lowest in all soil quality indicators, which may negatively impact long-term soil and tree health.

Application of clove oil herbicide resulted in lower leaf N (Table 2) and tree growth (Figure 2) in comparison to cultivation treatments, likely due to increased competition for water and nutrients from uncontrolled weeds. Despite reduced disturbance, this treatment did not have any significant positive effect on soil quality parameters. In contrast, *S. alba* seed meal amendment resulted in ample pools of available soil N (Figure 1), relatively good tree growth (Figure 2), and improved overall soil quality relative to the CLT treatments. However, leaf N did not reach acceptable levels and many of the other essential nutrients were lowest in this treatment (Table 2). Tree leaf chlorosis was observed following early season amendment in 2006 and may be the result of reduced soil iron availability. While tree leaves in the BHE system recovered, delayed production of leaf chlorophyll may have reduced the tree's ability to uptake and utilize available soil N. Additional research using different Brassicaceae species is needed to identify application rates and their timing to prevent tree damage.

Tree leaf Ca and Zn were below acceptable levels in all treatments, but were among the lowest in the cultivated treatments along with leaf P (Table 2). Interestingly, research has shown that root interaction with mycorrhizae, which is negatively impacted by soil tillage, can increase tree uptake of these elements. In our study, leaf concentrations of these elements were greatest among un-disturbed treatments (Table 2), implying that enhanced soil mycorrhizae in undisturbed systems may have facilitated greater Ca and Zn uptake. All other essential nutrients were within acceptable levels for all treatments (data not shown).

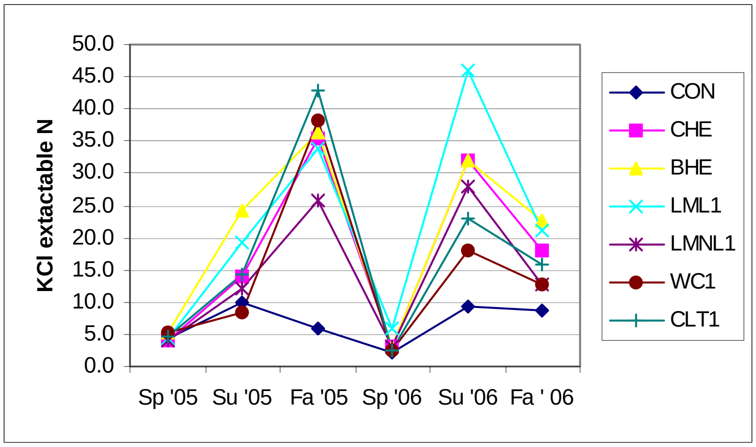

Figure 1. Plant available N (mg/kg) over time as determined by KCl extraction

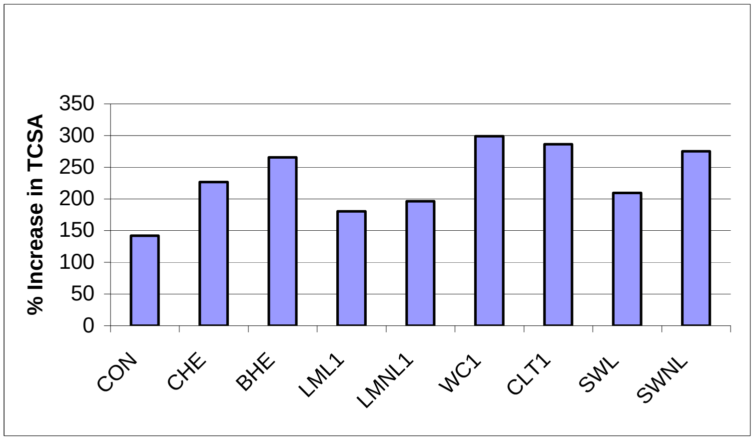

Figure 2. 2006 Percent increase in Tree Cross Sectional Area (TCSA)

Table 2. 2006 Tree Leaf Nutrient Data (Desired nutrient levels for young non-bearing apples 2.4-2.6% N, 0.22-0.3% P, 1.5-2.0% Ca, and 15-200 ppm Zn)

Treatment	% N	%P	% Ca	Zn ppm
CTL0	2.08 de	0.40 a	1.26 cd	9.47 abcd
CHE	2.35 abc	0.26 cd	1.31 abcd	10.49 ab
BHE	2.25 cde	0.21 d	1.17 d	10.33 abc
LML1	2.55 a	0.24 d	1.43 ab	10.37 ab
LMNL1	2.50 ab	0.24 d	1.37 abc	10.68 ab
WC1	2.05 e	0.38 ab	1.30 abcd	9.28 bcd
CLT1	2.45 ab	0.21 d	1.27 cd	9.36 bcd
SWL	2.33 abc	0.23 d	1.36 abc	10.18 abc
SWNL	2.29 bcd	0.23 d	1.44 a	9.3 abcd

Table 3. Total Carbon and Nitrogen (mg/kg) and Particulate Organic Matter Fraction (POM) C and N (mg/kg soil)

	2005		2006			
Treatment	**Carbon**	**Nitrogen**	**Carbon**	**Nitrogen**	**POM-C**	**POM-N**
CON	11172 ab	911 ab	11900 fgh	920 d	41.10 b	2.34 bc
CHE	9608 ab	732 ab	12500 defg	1100 bc	48.18 ab	2.94 abc
BHE	11015 ab	878 ab	13400 abcd	1200 ab	45.50 ab	2.92 abc
LML1	12255 a	939 a	14300 a	1240 a	50.06 ab	3.0 ab
LMNL1	11038 ab	822 ab	14600 a	1210 ab	55.26 a	3.28 a
WC1	10959 ab	844 ab	11600 ghi	920 d	39.21 b	2.11 c
CLT1	8841 b	683 b	10500 ij	800 ef	41.27 b	2.64 abc

SUMMARY

Nitrogen fertility in organic orchard systems is dependent upon build-up of soil organic matter and beneficial faunal communities, yet extensive cultivation is commonly used to control weeds, which can diminish the amounts and activity of these biologically based components. While intensive cultivation of the orchard understory results in healthy trees with good growth, this production system remains dependent on annual additions of amendments to meet fertility demands. In addition, results of this study indicate that intensive cultivation reduced various soil quality parameters, which may negatively impact long-term tree health and fruit quality. In contrast, the non-disturbed living mulch understory resulted in increased competition with orchard trees and a corresponding decrease in tree growth. Nevertheless, trees in this system appeared healthy in year two and possessed ideal leaf N values. Our indicators suggest that soil quality is improving and the living mulch system is more effective at retaining available N pools, which may have positive impacts on long-term tree health and result in a system that is more compatible with organic nutrient cycling dynamics. However, given the great competition of living mulch plants with young trees, a more desirable strategy during establishment may be application of low C:N ratio plant biomass that could improve soil quality without acting as a competitor to tree development. Although application of wood chip mulch has had positive impacts in previous studies, it did not perform well in the current study, resulting in low leaf N and poor performance on all soil quality indicators. Application of organically approved herbicides hold promise to reduce soil disturbance and improve soil quality over time, yet they will need to be more effective at controlling weeds that compete for N resources. Brassicaceae seed meal amendments have potential to simultaneously provide N as well as control weeds and soil-borne diseases, yet they require additional study to determine optimal rates and conditions for application in organic orchard management systems.

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