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Effects of Ground Cover Treatments on Growth and Photosynthesis in Young 'Enterprise' Apple Trees

Hyun-Sug Choi[1], and Curt R. Rom[2]

Abstract

Ground cover mulches were applied annually during the first three years from planting to 'Enterprise' apple (*Malus* × *domestica* Borkh.) trees on M.26 rootstocks. The ground cover treatments were: 1) green compost (GC), 2) wood chips (WC), 3) shredded paper (SP), and 4) mow-and-blow (MB). GC- and WC-treated mulches supplied greater amounts of total N, P, and K to the soil than the SP and MB mulches. GC plots had the highest soil pH, electrical conductivity, [P], and [K] in both years 2 and 3, except for soil pH at 10 to 30 cm depth in year 2. GC- and WC-treated trees had lower specific leaf areas and greater leaf N and shoot growth in year 2 as well as greater trunk cross sectional areas in years 2 and 3. SP trees had the lowest CO_2 assimilation and leaf chlorophyll concentration (SPAD) in year 2. GC and WC treatments would be suitable ground cover mulches from the aspect of tree growth, CO_2 assimilation, and reproductive capacity in establishing an organic orchard in the Southern USA apple growing region.

Ground cover treatments which cover the soil surface are used primarily for weed inhibition in organic farming systems (4). However, mulches have also been shown to conserve soil moisture, improve water infiltration, maintain optimal soil temperature, control weeds, and increase soil nutrition, resulting in enhanced tree growth and CO_2 assimilation (4, 29, 30). Weed management around apple trees is crucial for water and nutrient uptake to increase tree growth and CO_2 assimilation because apple trees have relatively sparse root systems and do not compete well for soil resources compared with weeds (1). However, previous ground cover studies were mostly conducted in the arid Pacific Northwest United States with little or no research done in the lower-Midwest or Southern US where the climate and soil types are markedly different.

The benefits of various ground covers depends on the type of mulch used. N mineralization rates in organic raw materials averaged 16%, 7%, and 1% of organic N during the 12 week periods of incubation for a manure, manure compost, and plant residue compost, respectively (15). Mineralized nutrients from the ground covers contribute to tree vigor, tree nutrition, and CO_2 assimilation. N in a leaf is a component of amino acids and chlorophyll pigment molecules as well as ribulose bisphosphate carboxylase, a key enzyme that is essential for CO_2 assimilation and plant growth (28). Foliar CO_2 assimilation would likely be affected by mulch type since foliar [N] has been shown to be related to CO_2 assimilation in plants (17), and has a curvilinear relationship in both apples (6, 32) and peaches (7). Furthermore, net photosynthetic rate and stomatal conductance decrease with decreasing leaf N, and photosynthesis-related enzymes are restricted by N-limitation in apple trees (5). However, few studies have been conducted in organic apple orchards to examine the effect of ground cover mulches on soil condition, tree growth, and photosynthesis.

An organic apple orchard, following USDA National Organic Program protocols, was established to examine the effect of ground cover mulches on tree growth and photosynthesis in the warm, humid, Southern US environment. Data and experiences obtained were used to develop appropriate organic orchard recom-

[1] Organic Agriculture Division, National Academy of Agricultural Science, Suwon, Gyeonggi-do 441-857, South Korea

[2] Department of Horticulture, University of Arkansas, Fayetteville, AR 72701
To whom requests should be addressed. Email address: crom@uark.edu

mendations for ground cover management.

Materials and methods

'Enterprise' apple (*Malus* × *domestica* Borkh.) trees on M.26 rootstocks were planted in an organically-managed orchard at the University of Arkansas Main Agricultural Experiment and Extension Center in Fayetteville, AR (36ºN, 94ºW) in March of 2006 (year 1). Average annual precipitation was 1,269 mm at Fayetteville from years 1 to 3, and the mean temperature was 14°C. The soil was a Captina silt loam formed on alluvial terraces with a pH of 5.5 (14), and was moderately well-drained. Before planting, the site had not been used for crop production and had not been in apple production during the past 30 years. There was extensive soil moving, grading, and tillage in late summer and fall in 2005 prior to the planting of the orchard the following year. The soil had approximately 1.0% organic matter, a moderately low cation exchange capacity of 8.7%, and moderate base saturation (43%; K 3.9%, Mg 6.5%, and Na 0.5%). Incorporation of lime at a rate of 900 kg·ha^{-1} was applied to adjust soil pH. Horse manure was applied at approximately 900 kg•ha^{-1} to increase soil fertility and was incorporated by tillage prior to planting a cover crop of K-31 tall fescue and a winter wheat nursery crop at a rate of approximately 122 kg·ha^{-1}. Trees were planted at 2 m spacing within rows and 4 m between rows for an approximate density of 1,250 trees per hectare. The trees were trained on a 3.5 m tall vertical axis with a 2-wire trellis system for tree support and training.

Ground cover mulch application

The ground cover treatments (GCT) included: 1) urban green compost (GC); 2) refuse wood chips (WC) from an urban arboriculture source of unknown origin; 3) shredded institutional "white" paper mulch (SP); and 4) mow-and-blow green mulch (MB) where the between-row fescue was mowed after seed head formation each spring and monthly through the season and simultaneously blown under the tree canopies with a side-discharge mower. Trees were not fertilized. On the mulched plots (GC, WC, and SP), an approximately 10-cm layer of mulch was initially applied only under the planted trees (0.4 m^3 of mulch around each tree) in April in year 1 and annually reapplied in a approximately 4 m^2 square area under the trees – extending 1m in each direction from a tree. A vegetated tractor drive row of 2 m width was maintained. The purpose of the ground cover treatments was for control of competitive undertree vegetation (weeds). Vegetation density was evaluated by digital image analysis (Model Olympus C3030Z, Olympus Optical Co., London, UK) and GC-, WC-, SP-, and MB-treated plots had 17, 19, 12, and 36% of vegetation density under trees in June in year 3, respectively.

Samples of the GCT were collected in May in years 2 and 3, using 1-m^2 quadrangle frames randomly positioned within the rows to estimate ground cover mulch biomass. Random samples of each mulch were dried and ground in a blade mill grinder. The samples were analyzed as a combined bulk sample for nutrient analyses at the UA Soil Analysis Laboratory. Total [N] and [C] were analyzed using a micro-Kjeldahl technique and dry combustion with, respectively, an N analyzer (Model FP 428, LECO Corp., St. Joseph, MI) and with a CN analyzer (Model CN 2000, LECO Corp., St. Joseph, MI) (Table 1). [P] and [K] were analyzed by Inductively Coupled Plasma Spectrometry (ICPS). Ground cover biomass per square meter was sampled and dried at 70°C for three days for measuring the dry weight in year 2. Additional mulch inputs in year 3 were estimated by measuring the additional amounts of each applied mulch although the actual N availability to each plot would have depended upon the N mineralized in each system. Total N, P, and K inputs from each mulch were then estimated by multiplying the mulch dry weight with the respective mineral concentrations in each mulch (27).

Fruit-bearing trees

In this trial, trees treated with GC and WC all exceeded 3.1 m total height at the end of

Table 1. Dry weight, nutrient concentration, and estimated amount of nutrients applied from ground cover treatments, averaged over two years (2007 and 2008) in an organic apple orchard, Fayetteville, AR.

Treatment	Dry wt (g)	Nutrient concentration (%, dry wt)			
		[C]	[N]	[P]	[K]
Green compost (GC)	31,602	14	1.0	0.15	0.40
Wood chips (WC)	23,406	22	0.5	0.05	0.20
Shredded paper (SP)	11,575	35	0.2	0.01	0.04
Mow-and-blow (MB)	798	34	2.0	0.24	0.91
	C:N ratio	Nutrient content applied ($g \cdot tree^{-1} \cdot year^{-1}$)			
		C	N	P	K
Green compost (GC)	14	5,467	396	57	151
Wood chips (WC)	39	5,522	135	13	51
Shredded paper (SP)	229	7,617	34	2	9
Mow-and-blow (MB)	15	550	31	4	15

the second season (year 2), the target M.26 tree height, and a spread of 2 m of the 3 m tree width allocated (data not presented). Therefore, GC and WC trees were allowed to crop in year 3 whereas the SP and MB trees were not allowed to fruit due to insufficient growth. In year 3, mean fruit dry weight of GC- and WC treatments were estimated to be 1.37 and 0.58 kg per tree, respectively, based on lypophilized subsamples of harvested fruit.

Nutrient analyses

Soil samples were collected with a 2-cm diameter soil probe taken at three points 50 cm from the tree trunk and at 0 to 10 cm and 10 to 30 cm depths in mid-May of years 2 and 3. Soils in May were sampled in order to evaluate soil nutrients immediately following annual mulch application in April. Each soil sample was passed through a 2 mm mesh sieve and analyzed by an auto-analyzer (Skalar Inc., Norcross, GA) to determine nitrate concentration. The remainder of the sample was air-dried, and the pH and electrical conductivity (EC; salt concentration) were measured. Other extractable nutrient concentrations were determined by the Mehlich 3 extractable method at the University of Arkansas Nutrient Analysis Laboratory.

Leaves were sampled following the method of Garcia (10) at approximately 100 days after budbreak of years 2 and 3. Leaves from a mid-shoot position of current year's shoots were sampled. Fresh leaf area, leaf weight, and specific leaf area were measured. Samples were then dried at 60°C and ground to pass through a 2 mm mesh screen. The ground leaf samples were analyzed using the micro-Kjeldahl technique and combustion with an N analyzer (Model FP 428, LECO Corp., St. Joseph, MI) for total [N] at the University of Arkansas Nutrient Analysis Laboratory.

Tree growth and gas exchange

Shoot length and tree trunk cross-sectional area (TCSA) 30 cm above the graft union were both measured in November of years 2 and 3.

Gas exchange measurements were taken between 0700 h and 1900 h (DST) in early July of year 2, and during July and August of year 3, for the measurement of diurnal CO_2 assimilation, using a portable gas exchange analyzer (CIRAS-1 Analyzer; PP Systems, Haverhill, MA) with a Parkinson's leaf cuvette and automatic light control (LED unit). The cuvette conditions were set at 25°C, 350 $mg \cdot L^{-1}$ CO_2, 50% relative humidity, and 1,200 $\mu mols \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux. Measurements were made on mid-shoot leaves of current year's shoots at shoulder height around the periphery of each sentinel tree. The SPAD 502 meter (Minolta, Japan) provided non-destructive measurement of colorimetric chlorophyll concentration of the leaf from May to September of year 2. Photosynthetic N use efficiency (PNUE) was calculated as carbon production (μmol $CO_2 \cdot s^{-1}$) per leaf N content (g).

Statistical analysis

The experimental design was a randomized complete block with six replications of each treatment. The data analysis was performed using the PROC GLM procedure of SAS statistical analysis software (SAS version 8.2, Cary, NC), and mean comparison was calculated by least significant difference (LSD, α = 0.05). Unless noted otherwise, only results significant at $P \leq 0.05$ are discussed.

Results

Nutrient analyses of mulches and soil

GCT differed in dry weight, [C], [N], [P], [K] and C:N ratio and provided a wide range of different nutrient concentrations to the orchard system (Table 1). The MB and GC mulch treatments had high [N], [P], and [K] and both had ideal C:N ratios of between 10:1 and 20:1 (9). SP mulch contained the lowest [N], [P], and [K] but the highest [C], resulting in the highest C:N ratio. GC and WC mulches had greater amounts of N, P, and K applied ($g \cdot tree^{-1} \cdot year^{-1}$) compared with either the SP or MB mulches.

The soil pH was generally higher in the GC and SP plots at both soil depths in each year (Table 2) and GC had the highest soil EC at both soil depths in each year. All EC values were lower than the 0.5 $ds \cdot m^{-1}$, which was observed in an organic orchard in Washington State in US (12) but similar to an apple orchard that had been treated with various mulches in Western Canada (23). Inorganic soil [N] ($NO_3^- + NH_4^+$) at 0 to 10 cm soil depth was significantly affected by ground cover mulches in both years 2 and 3 (Table 2). GC, which supplied greater amounts of N from the raw biomass (Table 1), produced the highest inorganic soil [N] in the 0 to 10 cm soil horizon in year 2, and SP had the lowest value. The MB mulch produced the greatest inorganic [N] in the same soil horizon in year 3 even though the MB-treated plots received the lowest supplemental N (Table 1). Inorganic [N] in the 10 to 30 cm soil horizon was not affected by ground cover mulches in either year (Table 2). Annual application of GC resulted in higher [P] at both soil depths in both years 2 and 3 which is consistent with the high amounts of P being applied in this treatment (Table 1). Soil [K] was affected by ground cover mulches with the GC plots consistently having the highest soil [K] and MB plots the lowest.

Tree growth and foliar gas exchange

Trees growing in plots treated with SP had the highest specific leaf area (SLA) in year 2, but no differences for SLA were observed in year 3 ($P = 0.055$) (Table 3). SLA increased by 36% on average from years 2 to 3. The lowest leaf N content per unit leaf area ($mg \cdot cm^{-2}$) also occurred in SP trees in year 2, and the trees treated with GC had a greater leaf N content in year 3 compared with the other ground cover treatments. GC and WC trees had greater shoot growth in year 2 and greater trunk cross sectional area (TCSA) in both years than either the SP or the MB trees. As observed in shoot growth, the TCSA percentage increase was large and different amongst the treatments in year 2 but these increases were smaller in year 3. SP had the lowest TCSA percentage increase in year 2.

Gas exchange values in Table 3 are averages of readings taken between 0900 hr and 1500 hr (DST) using a portable gas exchange analyzer over the two years of the study. There was no effect of ground cover mulch applications on either foliar transpiration (Tr) or stomatal conductance (g_s) (data not presented). However, ground cover mulches in both years affected internal [CO_2] (CI) and Pn with lower values consistently occurring in the SP treatment. All ground cover-treated trees had similar photosynthetic N use efficiency (PNUE) in each year of the study. Overall diurnal CO_2

Table 2. Soil pH, EC (electrical conductivity), inorganic [N] ($NO_3^- + NH_4^+$), available [P], and [K] in an organic 'Enterprise' apple orchard as affected by ground cover treatments in years 2 (2007) and 3 (2008).

Treatment	pH	EC ($ds \cdot m^{-1}$)	Inorganic [N] ($mg \cdot kg^{-1}$)	[P] ($mg \cdot kg^{-1}$)	[K] ($mg \cdot kg^{-1}$)	pH	EC ($ds \cdot m^{-1}$)	Inorganic [N] ($mg \cdot kg^{-1}$)	[P] ($mg \cdot kg^{-1}$)	[K] ($mg \cdot kg^{-1}$)
	0-10 cm depth					10-30 cm depth				
	Year 2									
Green compost (GC)	7.3 a[z]	0.112 a	8.7 a	44 a	228 a	6.1 b	0.053 a	3.6	28 a	132 a
Wood chips (WC)	6.9 b	0.090 b	6.9 ab	33 b	139 b	6.1 b	0.033 b	3.2	21 b	92 b
Shredded paper (SP)	7.3 a	0.073 b	6.1 b	26 b	85 c	6.4 a	0.035 b	2.8	18 b	48 c
Mow-and-blow (MB)	6.9 b	0.063 b	6.6 ab	27 b	80 c	6.0 b	0.028 b	3.0	24 ab	40 c
P value	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	ns	<0.001	<0.001
	Year 3									
Green compost (GC)	7.7 a	0.222 a	24.9 b	72 a	312 a	7.0 a	0.125 a	18.0	43 a	157 a
Wood chips (WC)	7.2 b	0.151 b	24.8 b	36 b	171 b	6.8 b	0.079 b	12.9	22 b	87 b
Shredded paper (SP)	7.7 a	0.194 a	26.2 b	35 b	133 b	7.1 a	0.079 b	12.6	19 b	50 c
Mow-and-blow (MB)	6.9 c	0.174 ab	38.6 a	31 b	87 b	6.6 b	0.091 ab	15.1	24 b	46 c
P value	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.05	ns	<0.001	<0.001

[z] Mean comparisons among treatments within a column by LSD; means followed by different letters are significantly different, 5% level. ns = not significantly different. pH and EC were determined in 1:2 soil:water suspension.

Table 3. SLA (specific leaf area), leaf N, current shoot growth, TCSA (trunk cross sectional area), TCSA incr (TCSA increase), [CI] (internal CO_2 concentration), CO_2 assimilation, and PNUE (photosynthetic N use efficiency) of 'Enterprise' apple trees in an organic orchard as affected by ground cover treatments in years 2 (2007) and 3 (2008).

Treatment	SLA ($cm^2 \cdot g^{-1}$)	Leaf N ($mg \cdot cm^{-2}$)	Shoot length (cm)	TCSA (cm^2)	TCSA incr (%)	[CI] ($mg \cdot kg^{-1}$)	Pn[z] ($\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$)	PNUE ($\mu molCO_2 \cdot g^{-1}N \cdot s^{-1}$)
				Year 2				
Green compost (GC)	85 b[y]	0.24 a	3,751 a	1,683 a	173 a	192 b	15.5 a	6.66
Wood chips (WC)	85 b	0.25 a	3,209 a	1,523 a	164 a	195 b	15.4 a	6.57
Shredded paper (SP)	94 a	0.18 b	503 b	497 b	26 b	246 a	10.1 b	6.84
Mow-and-blow (MB)	84 b	0.24 a	1,067 b	705 b	99 ab	205 b	16.0 a	7.01
P value	< 0.01	< 0.001	< 0.001	< 0.001	<0.05	<0.001	<0.001	ns
				Year 3				
Green compost (GC)	106	0.23 a	4,605	2,750 a	64	215 b	12.8	5.67
Wood chips (WC)	121	0.19 b	4,294	2,439 a	58	222 b	12.9	6.90
Shredded paper (SP)	127	0.16 b	1,401	988 b	70	238 a	12.1	7.71
Mow-and-blow (MB)	125	0.19 b	2,683	1,274 b	98	221 b	13.0	7.01
P value	ns	< 0.01	ns	< 0.001	ns	<0.05	ns	ns

[z] Presented value is an averaged reading between 0900 and 1500 hr, which was taken with a portable gas exchange analyzer (CIRAS-1 Analyzer, PP Systems, Haverhill, MA). Values were averaged over the two years of the study.

[y] Mean comparisons among treatments within a column by LSD; means followed by different letters are significantly different, 5% level. ns = not significantly different.

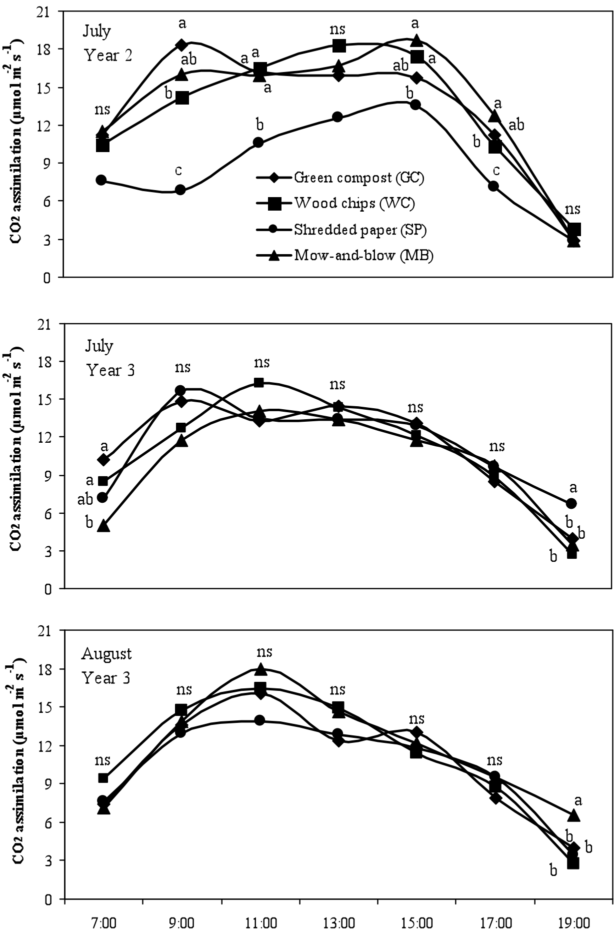

Fig. 1. Leaf CO_2 assimilation of 'Enterprise'/M.26 apple trees in an organic orchard as affected by ground cover treatments in July of year 2 (2007) and in July and August of year 3 (2008).

Different letters adjacent to data points indicate significant difference as determined by LSD, 5% level. ns = not significantly different.

assimilation correlated with a previous study (11); increasing at sunrise, fluctuating during the afternoon, and then decreasing at sunset (Fig. 1). SPAD readings increased from May to June and then remained fairly constant until September (Fig. 2). The SP-treated trees had lower SPAD readings throughout the season. Leaf area, SLA, leaf N, and SPAD readings in year 2 strongly correlated with averaged CO_2 readings between 0900 hr and 1500 hr (DST) in that year (Table 4).

Discussion

The optimum C:N ratio (between 10:1 and 30:1) in all of the mulches had provided sufficient available N for the trees assuming that there was adequate soil microbial activity. This ratio is considered to be an indicator of the available N released from fresh crop residues or manures (9). GC and WC mulches, as sources of considerable raw biomass, supplied greater N, P, and K per tree in each year of the study (Table 1). GC mulch supplied about 10

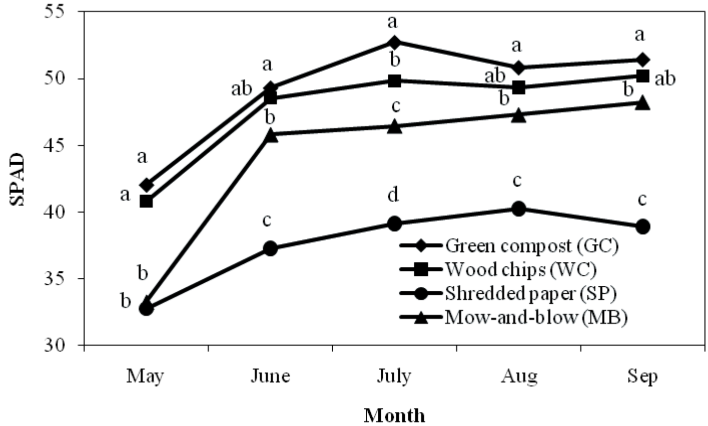

Fig. 2. Minolta SPAD 502 meter chlorophyll estimate of leaves of 'Enterprise'/M.26 apple trees in an organic orchard as affected by ground cover treatments from May to September of year 2 (2007).
Different letters adjacent to data points indicate significant difference as determined by LSD, 5% level.

times greater N (396 g) than the SP (34 g) and MB (31 g) mulches, with the latter being less than the 50 g of N required annually per tree (8). N–mineralization dynamics will follow different trends due to the different C:N ratios of applied GC, WC, SP, and MB – from rapid and high N flow from mineralization of green compost to possible N-immobilization from shredded paper. The high C:N ratio of 39:1 in the WC mulch induced slow N-mineralization (Table 2), which produced a similar soil inorganic [N] in year 2 to the MB mulch that had a lower C:N ratio of 15:1. The highly mineralized N in GC plots would likely have been taken up by trees or other vegetation (weeds), or might have been leached out of the system, resulting in similar inorganic [N] between the ground cover-treated plots. MB plots had the highest inorganic [N] in the top soil fraction in year 3 since plots without a completely protected soil surface could have mineralized N after the temperature increased in spring. However, temperatures in the deeper soil did not affect N mineralization under the different mulches in both years 2 and 3.

Greater soil pH at both depths of 0 to 10 and 10 to 30 cm in the SP plots (Table 2) could have been caused by the high calcium carbonate content in the paper (24), which has also been observed elsewhere (23). All treatments increased soil EC by 57% from years 2 to 3, with the GC plot having greater EC, which may be an indication of more available [NO_3^-] in the soil in year 2 (Table 2). However none of the plots exceeded 1 ds•m^{-1} EC, which is the potential salinity value for yield and growth reduction of apple trees (21).

Each of the ground cover treatments increased soil inorganic [N] from years 2 to 3 (Table 2) and were effective in increasing and maintaining [N]. However, it is accepted that only one measure of soil mineral [N] in May is not adequate to evaluate soil [N] conditions due to the lability of [N] in the soil or due to leaching and other factors. Higher organic matter and microbial biomass contributed to N mineralization from mulches in other studies (26, 29), so we expected to find higher levels of mineralized N from the organic materials in subsequent years in this study. In one particular study (18), [C], [N], and mineralizable [N] were not changed in an organic farming system for 3, 9, or 41 years although microbial biomass increased significantly. Soil [P] ranged about 18 to 43 mg•kg^{-1} in the 10 to 30 cm depth over both years, which was ten-times the suggested level of P nutrition for Eastern orchards in US (31) and was much greater than that determined in an organic apple orchard (22). The soil [K] averaged less than 70 mg•kg^{-1} in the SP and MB plots which is below the suggested range for soil [K] (31). Mobile soil [K] is leachable from a tree root zone, and the [K] loss could have been stimulated in the MB plots where tilling was used and where the hydraulic conductivity may have been higher (16).

SLA and leaf N are strongly correlated to the photosynthetic photon flux received by leaves (3). Higher values of SLA and lower leaf N in year 3 compared with year 2 could have been offset by or attributed to incremental tree growth (TCSA) (Table 3). Larger trees tend to reduce light interception by their inner canopies due to shading, which result in smaller numbers of palisade layers, and lower chlorophyll and N content in leaves from such positions in the tree (3). We observed a similar trend in this study: lower leaf N, and higher SLA and TCSA in year 3 compared with year 2. Notably, GC- and WC-treated plots reduced their rapid size growth in year 3 probably as they approached a mature, fruit-bearing size. In year 3, the TCSA increases (%) were non-significant between ground cover treatments but the relative increases between years in both SP and MB trees were substantially greater than in the GC and WC trees.

Tree growth appeared to be more affected by N input from the mulch rather than by soil inorganic [N] since GC and WC mulches supplied much larger amounts of N compared to SP and MB mulches, which would likely have led to increased TCSA in years 2 and 3. Inorganic [N] in the 10 to 30 cm soil depth in years 2 and 3 had weak correlations with SLA, leaf N, shoot growth, and TCSA (data not presented). Also, no positive correlations between soil and leaf [P] and [K] were observed in either year (data not presented). The trees would have been deep-rooted in the soils in years 2 and 3, and the soil samples, collected at a relatively shallow depth, may not have reflected soil nutrient values at a greater depth (31).

Overall, CO_2 assimilation rates averaged over the two years (Table 3) were similar to or slightly lower than the 15 µmol CO_2•m^{-2}•s^{-1} previously determined in healthy exposed apple leaves (20). Assimilation rates of greater than 15 µmol CO_2•m^{-2}•s^{-1} in year 2 were observed in the GC, WC, and MB trees all of which had both lower SLA and higher leaf N. Previous studies have shown that cropping trees have higher photosyntheic rates than non-cropping trees (13, 25) because leaves in non-cropping trees are sink-limited (33). In our study, non-cropping trees within the SP and MB treatments had similar photosynthetic rates to those of the cropping GC and WC trees in year 3 possibly due to enhanced TCSA increases (Table 3). Previous studies have shown that PNUE of apple leaves decreases with increasing leaf [N] (2, 6). In our study,

Table 4. Correlation coefficients of leaf area, specific leaf area (SLA), leaf N, current shoot growth, TCSA (trunk cross sectional area), and SPAD for CO_2 assimilation in an organic apple orchard as affected by ground cover treatments in year 2 (2007).

Variables	Year 2	
	Significance	R2
Leaf area	<0.001***	0.731
Specific leaf area (SLA)	<0.001***	0.514
Leaf N	<0.001***	0.684
Total shoot length	0.013*	0.269
TCSA	0.007**	0.299
SPAD	<0.001***	0.644

*, **, ***Significantly different means at $P < 0.05$, 0.01, and 0.001, respectively.
CO_2 value is an averaged reading between 0900 and 1500 hr, which was taken with portable gas exchange analyzer.

GC and WC trees had a higher leaf N content but differences in PNUE were non-significant. The post-midday decline in CO_2 assimilation was characteristic and likely due to the accumulation of assimilates and feedback inhibition (13). SP trees maintained lower foliar CO_2 assimilation throughout the day in year 2 but not in year 3.

In pear trees, the effect of leaf [N] on net photosynthesis rates was associated with chlorophyll concentrations and enzyme production (19). In our study, there was a positive linear correlation between leaf N and CO_2 assimilation in year 2 ($R^2 = 0.644$). GC mulch in this study improved SLA, leaf N, shoot growth, and TCSA apparently because there were greater total amounts of N available to the tree. However, no significant correlations between leaf area, SLA, leaf N, and TCSA and photosynthetic assimilation rate were found in year 3 where there were no inter-plot differences in CO_2 assimilation.

Conclusions

Differences in total N input and C:N ratios, as provided by the various ground cover mulches, affected soil inorganic [N], tree growth, leaf development, and CO_2 assimilation in year 2. In particular, trees from the GC and WC treatments grew faster and came into bearing earlier than the trees in the other mulch treatments. Differences in year 3 were diminished because the GC and WC trees were vigorous enough to be self-shading. These particular ground cover treatments would be suitable in warm and humid climates of Southern US to enhance soil conditions, soil fertility and plant growth.

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Erratum

Page numbering in Volume 65 (2) did not follow in sequence from 65 (1) as is the usual style for the journal. Page numbering for 65 (2) was specific for that issue. This was a printing error. Citations for papers in 65 (2) must, therefore, include the issue number.

Page numbers for 65 (3) have been set to be continuous within the volume, as is the usual style for the journal.