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Plant Performance, and Seasonal Soil and Foliar Nutrient Variations in an Organic Apple Orchard under Four Ground Cover Management Systems

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Abstract

A mature apple (*Malus* × *domestica* Borkh.) orchard was converted to an organically managed system to evaluate the effects of four ground cover management systems (GMS) on soil and foliar nutrient status after 3, 5, and 6 years (2002, 2004, and 2005, respectively) across three cultivars. GMS treatments were applied annually during years 1-6 as follows: wood chips (WC); shredded paper (SP); mown vegetation (Mow); and black fabric cloth (BFC) to mature trees of 'Braeburn', 'Gala', and 'Jonagold' growing on M.9 rootstocks. SP plots had greater soil moisture content in year 4 and a faster water infiltration rate in mid-summer of year 6 compared with the WC, Mow, and BFC plots. WC plots had greater organic matter, [NO_3^-], [Mg], and [B] in soil compared with the other GMS plots. A higher foliar [Mn] was observed on the Mow and BFC plots where soil pH was lower than 6.0 in year 6. Generally, all GMS trees had decreasing foliar [N], [P], and [K] and had increasing [Ca] and [Mg] from April to September in year 6; these concentrations were similar to seasonal foliar nutrient patterns reported for conventional orchards. GMS mulches did not affect tree growth and yield, but cultivars did respond differently.

Consumer demand and willingness to pay premium prices for organic fruits have caused transitions from conventional to organic fruit production (6, 10, 25, 38). Living and organic ground cover management systems (GMS) can have a wide range of, sometimes contradictory, effects on nutrient levels in soil and trees, depending on the ground cover type, soil chemistry, and the particular nutrients of interest (4). Only a few studies in the Pacific Western USA (2, 26, 34) and Canada (22) have compared the foliar nutrients of organic apple orchards with those in conventionally managed orchards. Likewise, there has been only limited research in the warm, humid Southern USA. Organic farmers have applied organic fertilizers based on recommendations for fertilizer applications in conventional orchards (35). However, organic fertilizer applications may provide or release different amounts of soluble nutrients into the soil during a growing season compared with conventional soluble fertilizers.

Foliar nutrient analysis in mid- to late summer is useful for diagnosing the nutrient status of apple trees and is used to formulate fertilizer recommendations (7, 33, 37). Early or seasonal nutrient analysis can also provide information to indicate when critical nutrients are required for tree growth and development (1). The seasonal nutrient variation within apple leaves can illustrate critical nutrient requirements and serve as the basis for recommending appropriate fertilizer applications (1, 16, 18). Foliar nitrogen (N), phosphorus (P), and potassium (K) concentrations normally decrease during summer because those elements move to new leaves (1, 5, 7, 16, 17, 18, 24, 29, 37). Calcium (Ca) also accumulates and increases in leaves during the season. However, most seasonal data for apple leaf nutrient status have been developed in conventional orchards where synthetic soluble fertilizers, herbicides, and pesticides have been used (1, 5, 6, 18, 24).

Seasonal soil nutrient analysis provides ad-

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ditional information necessary to interpret the results of seasonal foliar analysis for a fertilizer application program (33). Both analyses are necessary to fully determine how nutrients should be applied to correct specific nutrient problems in the soil and plant (11). This study was established to investigate annual and seasonal nutrient concentrations within soil and leaves in order to understand how nutrient variations are related, how the nutrient status changes, and how organic production systems affect soil and foliar nutrients in the warm, humid, Southern environment of the USA.

Materials and methods

Plant material and treatment applications

The experiment was initiated in year 1 (2000) on 9-year-old, central leader axis trees of 'Braeburn', 'Gala', and 'Jonagold' (*Malus* × *domestica* Borkh.) on M.9 rootstocks with a 1.5 m (in row) × 3 m (between rows) spacing at the University of Arkansas Main Agricultural Experiment and Extension Center in Fayetteville (36ºN, 94ºW), USA. The soil series on the site was a mixture of a Captina and Pickwick silt loams with pH 5.5. The four ground cover management systems (GMS) that were used included uncomposted wood chips (WC), shredded white paper (SP), mown vegetation and partial cultivation (Mow), and black landscape fabric cloth (BFC). WC and SP treatments were applied annually in 5- to 7-cm thick layers approximately 1.5 m by 1.5 m areas under the tree canopy from years 1 (2000) to 6 (2005), and BFC was laid down in year 1. The Mow treatment was sprayed with contact herbicide (glyphosate) during the year 1 and mowed and partially cultivated in subsequent years. A formulated, certified organic pelletized fertilizer (10N-2P_2O_5-8K_2O, Nature Safe®, Griffin Inc., Cold Spring, KY) was applied each April at a rate equivalent to approximately 450 g of N per tree per year based upon local protocols (8). Certified organic materials were used for pest management, including pheromone mating disruption, sticky traps, lime sulfur, and 5% (w/v) of a highly refined kaolin clay (Surround™, Engelhard Corp., Iselin, NJ).

The mulches that were used had the following compositions (dry weight basis): WC contained 0.7% [N], 0.06% [P], 0.25% [K], 1.3% [Ca], 0.09% [Mg], 1,704 mg·kg^{-1} [Fe], 258 mg·kg^{-1} [Mn], 29 mg·kg^{-1} [Zn], 9 mg·kg^{-1} [Cu], and 10 mg·kg^{-1} [B]; SP contained 0.2% [N], 0.01% [P], 0.03% [K], 5.5% [Ca], 0.07% [Mg], 957 mg·kg^{-1} [Fe], 9 mg·kg^{-1} [Mn], 16 mg·kg^{-1} [Zn], 3 mg·kg^{-1} [Cu], and 2 mg·kg^{-1} [B]; and Mow contained 1.7% [N], 0.23% [P], 1.02% [K], 0.7% [Ca], 0.14% [Mg], 759 mg·kg^{-1} [Fe], 128 mg·kg^{-1} [Mn], 25 mg·kg^{-1} [Zn], 7 mg·kg^{-1} [Cu], and 6 mg·kg^{-1} [B].

Soil moisture measurement

Soil moisture readings were taken at two randomly-selected spots under the tree canopy at least 50 cm from the tree trunk for each treatment with a volumetric Theta-probe (Type ML2, Delta-T Devices, Cambridge, England) in July of years 2 and 4. Water infiltration (mL·min^{-1}) at the soil surface was measured within 15-cm-diameter single rings to determine the amount of water to be absorbed in June and September of year 6 at a point midway between the edge of the canopy and the trunk (15). No supplemental irrigation was applied in year 6. Annual precipitation is 1,269 mm at Fayetteville, and the mean temperature is 14ºC.

Soil sampling and analyses

Soil samples were collected monthly with a 2-cm-diameter soil probe at three different points 50 cm from each tree trunk at depths of 0-15 and 15-30 cm from April to October in year 6. The soil samples were passed through a 2-mm mesh sieve and analyzed by a colorimetric method on an auto-analyzer (SKALAR, Norcross, GA) for nitrate. The remainder of the sample was air-dried and tested for soil pH, electrical conductivity (EC), and the concentrations of specific mineral nutrients. The percentage of weight loss-on-ignition (LOI) in the soil was calculated using the method of Schulte and Hopkins (31). Soil organic matter (OM) was then estimated from the LOI according to the formula: (0.7 × LOI) - 0.23 =

OM (%) (13). The mineral nutrient concentrations were determined using the Mehlich-3 test at the University of Arkansas Nutrient Analysis Laboratory.

Foliar sampling and analyses

Leaves at an intermediate position on current season's shoots were sampled in August of years 3 and 5, and from April to September in year 6 for nutrient analysis. The sample leaves were washed and placed in an oven at 60ºC for 24 h and ground to pass through a 2-mm mesh screen. Total N was analyzed using the micro-Kjeldahl techniques and a combustion nitrogen analyzer (LECO FP 428, St. Joseph, MI). Other nutrient concentrations were determined by inductively coupled plasma spectrometry at the University of Arkansas Nutrient Analysis Laboratory.

Vegetation density and tree measurement

Under-tree vegetation density was visually rated in August of years 2 and 6 to estimate the percentage of ground covered by weeds (19). Apples were harvested at maturity in years 1, 2, 3, and 6. Fruit quality was evaluated on ten randomly-selected fruit per tree in years 1 and 2. Soluble solids concentration was measured using a refractometer (ATAGO, Japan), and fruit firmness was tested by using a penetrometer (Wagner Inc., Greenwich, CT). Starch rating (%) was determined by dipping a portion of the apple into an iodine solution and then comparing the fruit color change to a pictorial chart. The scale of starch was 0 to 12 where the greatest and lowest levels of starch were 0 and 12, respectively. Tree trunk cross-sectional area (TCSA) was measured at 30 cm above the graft union of each tree in November of years 3 and 6. Yield efficiency was calculated as the average yield divided by TCSA ($kg \cdot cm^{-2}$).

Statistical analysis

Not all variables were measured annually and variables are only statistically compared among treatments within a single year. The study was a randomized complete block design with five replications. Data analysis was performed using the PROC GLM procedure of the statistical analysis system (SAS Institute version 8.2, Cary, NC) (30), and mean separation was conducted using least significant difference (LSD, $\alpha = 0.05$). Regression analysis was carried out using PROC REG (SAS). Unless noted otherwise, only results significant at $P \leq 0.05$ are discussed.

Results

Few interaction and cultivar effects were observed for the different seasonal soil and foliar nutrient values in year 6 and main treatment effects are discussed in most instances.

Soil moisture and infiltration rate

A higher soil moisture content was observed for shredded paper (SP)-treated plots in years 2 and 4, and mow (Mow)-treated plots had the lowest moisture content in year 4, followed by black fabric cloth (BFC) plots (Table 1). The BFC treatment had the slowest infiltration rate in June (91 $mL \cdot min^{-1}$) and September (61 $mL \cdot min^{-1}$) of year 6, whereas the SP treatment with the highest soil moisture (0.22 m^3 $H_2O \cdot m^{-3}$ soil) in year 4 had the fastest infiltration rate (625 $mL \cdot min^{-1}$) in June and September (although not statistically significant) of year 6 (Table 1).

Seasonal soil pH and OM in year 6

SP-treated plots had the highest soil pH at the depth of 0-15 cm in June, July, and August (Table 2) and at the 15-30 cm depth in June. Wood chip (WC) plots had the greatest soil OM at the depth of 0-15 cm from April to October (Fig. 1A). The OM in the WC treatment was approximately 1.5% except in May and September, and the OM in the other GMS mulches did not change at the depth of 0-15 cm throughout each season. However, soil OM in Mow- and WC- treated plots were higher than other mulches at a depth of 15-30 cm in October (Fig. 1B).

Seasonal soil nutrient variations in year 6

Seasonal soil nutrient variations at the depth

Table 1. Soil moisture and infiltration rate in an organic apple orchard as affected by ground cover management systems (GMS) in mid-summer of years 2 (2001), 4 (2003), and 6 (2005).

Treatment	Soil moisture (m^3 H_2O•m^{-3} soil)		Infiltration rate (mL•min^{-1})	
	July, Year 2	July, Year 4	June, Year 6	Sep, Year 6
Wood chips (WC)	0.11 b[z]	0.14 b	227 bc	172 b
Shredded paper (SP)	0.19 a	0.22 a	625 c	185 b
Mow (Mow)	0.12 b	0.07 d	114 ab	147 b
Black fabric cloth (BFC)	0.16 ab	0.11 c	91 a	61 a

[z] Means followed by the same letter within a column are not significantly different according to LSD (α < 0.05, n = 15).

of 0-30 cm were observed from April to October in year 6. After annual ground cover treatments and fertilizers were applied in mid-April, soil nitrate concentration ([NO_3^-]) increased from April to June and slightly decreased subsequently for all the GMS mulch treatments (Fig. 2A). Soil [NH_4^+] peaked in May or June (Fig. 2B). The soil [NH_4^+] correlated with soil pH in September ($R^2 = 0.45$) and October ($R^2 = 0.52$) in year 6 (Figs. 3A and 3B). Although differences in soil [Mn] were not observed in all the GMS treatments, it was constantly high in the Mow and BFC plots from June to October (Fig. 2C).

Seasonal soil [P] varied over the season during year 6 and no differences were determined among treatments (Fig. 4A). Soil [K] had very similar patterns to soil [NO_3^-], increasing until June but had a drop in July with all GMS mulches (Fig. 4A). Soil [Ca], [Mg], and [B] each showed significant differences among GMS treatments during the April to October period. The SP treatment had higher soil [Ca] and [Zn] than other treatments, and the WC treatment had higher soil [Mg] and [B]. BFC had consistently lower [Ca], [Mg], and [B] than other treatments. Soil [Fe] was negatively correlated with soil pH at the depth of 0-15 cm in August (Fig. 5A).

Foliar nutrients in August; years 3, 5 and 6

There were few interactions or main effects (GMS and cultivar) on the foliar nutrient concentrations measured in August of years 3, 5, and 6 (Tables 3 and 4). No GMS mulch effects were observed for foliar [N] in years 3 ($P = 0.342$) and 6 ($P = 0.347$) (Table 3). The effects of GMS or cultivar effects on all other foliar macronutrients and micronutrients varied amongst years, and few differences

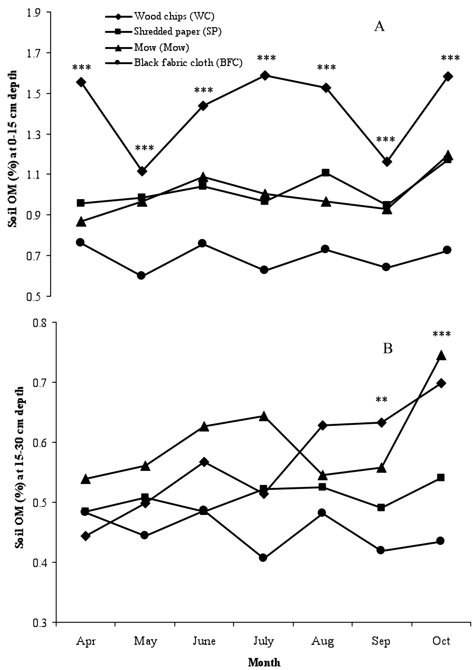

Fig. 1. Seasonal soil organic matter (OM) at depths of 0-15 cm (A) and 15-30 cm (B) in an organic apple orchard as affected by ground cover management systems (GMS) from April to October of year 6 (2005).
**, ***Significantly different means among ground cover management systems for a particular month at $P < 0.01$ and 0.001, respectively.

Table 2. Soil pH at depths of the 0-15 cm and 15-30 cm in an organic apple orchard as affected by ground cover management systems (GMS) in June, July, and August of year 6 (2005).

Treatment	pH					
	June	July	August	June	July	August
	0-15 cm depth			15-30 cm depth		
Wood chips (WC)	6.1 b[z]	5.9 b	6.1 b	5.9 ab	5.8	6.0
Shredded paper (SP)	6.6 a	6.2 a	6.4 a	6.2 a	6.0	6.1
Mow (Mow)	6.0 b	5.7 b	5.8 c	5.7 bc	5.5	5.6
Black fabric cloth (BFC)	5.7 b	5.7 b	5.6 c	5.4 c	5.7	5.4
					ns	ns

[z] Means followed by the same letter within a column are not significantly different according to LSD (α < 0.05, n = 15). ns = not significantly different.

Table 3. Foliar macronutrient concentrations of cultivar/M.9 apple trees in an organic orchard as affected by ground cover management systems (GMS) and cultivar in August of years 3 (2002), 5 (2004), and 6 (2005).

Treatment	Leaf macronutrient concentration (%, dw)							
	N		P			K		
	Yr 3	Yr 6	Yr 3	Yr 5	Yr 6	Yr 3	Yr 5	Yr 6
GMS								
Wood chips (WC)	2.08	1.93	0.16	0.14	0.092	1.16	1.40	1.44
Shredded paper (SP)	1.91	1.83	0.24	0.15	0.089	1.19	1.40	1.17
Mow (Mow)	1.94	1.95	0.18	0.13	0.087	1.11	1.31	1.30
Black fabric cloth (BFC)	1.84	1.98	0.18	0.13	0.090	1.10	1.16	1.20
	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar								
Braeburn	2.09 a[z]	2.00	0.21	0.14	0.090 b	1.14	1.22	1.36
Gala	1.97 a	1.90	0.20	0.14	0.094 a	1.19	1.41	1.13
Jonagold	1.75 b	1.86	0.17	0.13	0.083 c	1.09	1.37	1.31
		ns	ns	ns		ns	ns	ns
P value								
GMS	0.342	0.347	0.493	0.254	0.262	0.894	0.372	0.345
Cultivar	<0.01	0.079	0.289	0.226	<0.01	0.701	0.535	0.272
GMS × Cultivar	0.450	0.984	0.709	0.845	0.707	0.826	0.374	0.731

[z] Means followed by the same letter within a column are not significantly different according to LSD (α < 0.05, n = 6). ns = not significantly different.

among the treated trees were observed (Table 4). There were, however, interactions between GMS and cultivar for foliar [N] and [Mn] in August of year 5 (Table 5). WC+Gala and BFC+Gala trees had the highest foliar [N] (2.23%) and [Mn] (170 mg·kg^{-1}), respectively. Among all the mineral nutrients investigated in this study, a correlation between soil and foliar concentration was observed only for [Mg] (Fig. 6).

Leaf [Mn] was negatively correlated with soil pH at a depth of 0-15 cm in August of year 6 (Fig. 5B).

Seasonal foliar nutrient variations in year 6

Seasonal foliar nutrient variations in trees

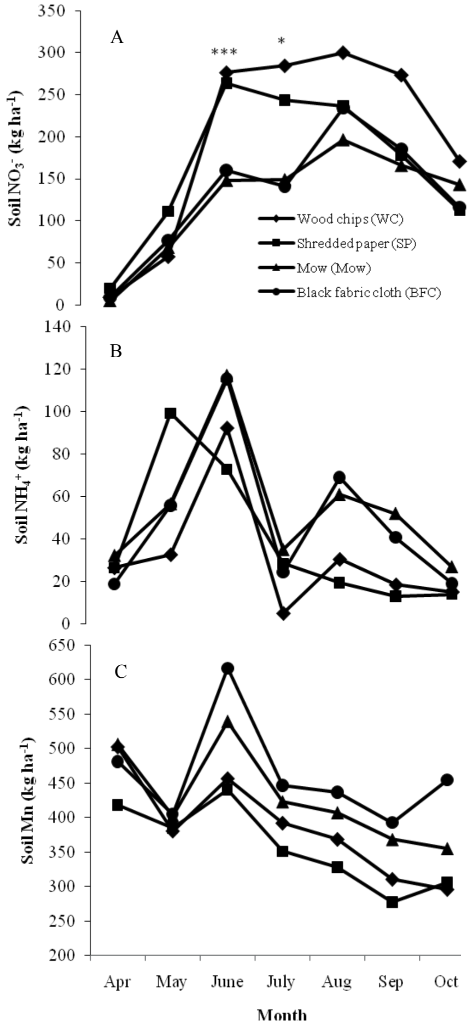

Fig. 2. Seasonal soil [NO_3^-] (A), [NH_4^+] (B), and [Mn] (C) at the depth of 0-30 cm in an organic apple orchard as affected by ground cover management systems (GMS) from April to October of year 6 (2005).
*, **, ***Significantly different means among ground cover management systems for a particular month at *P <0.05,* < 0.01 and 0.001, respectively.

grown under GMS in year 6 (Figs. 7A and 7B) tended to follow the nutrient concentration patterns as reported in conventional apple orchards. Foliar [N], [P], [K], and [Cu] decreased from April to September, while [Ca], [Mg], and [B] accumulated in leaves. Very few differences were observed amongst GMS treatments for any of the foliar macronutrients during year 6.

Fruit yield, tree growth, and vegetation density
Fruit yield was not affected by GMS mulches for any of the cultivars in year 1 (Table 6). In year 2, fruit yield was highest for both 'Gala' and 'Jonagold' in the WC treatment. In both years 1 and 2, fruit quality attributes were affected by GMS mulches but differences were minor and trends were not consistent amongst cultivars. No interaction effects of GMS x cultivar or any GMS effects were observed for the trunk cross sectional area (TCSA), yield, and yield efficiency values in either years 3 or 6 (Table 7). Overall, 'Braeburn' trees had a smaller TCSA in years 3 and 6, as well as a lower fruit yield, compared with 'Gala' and 'Jonagold' trees (Table 7). Mow-treated plots had the highest vegetation density in year 2, but this was markedly reduced in year 6 (Fig. 8) as the plots were partially cultivated to preventing the severe vegetation buildup that occurred in year 2. SP plots were the only plots with a higher vegetation density in year 6 than in year 2. BFC and WC plots maintained a low vegetation density in both years 2 and 6.

Discussion

Chalker-Scott (4) found that mulched plots have greater soil water content compared with bare soil, except for the ones with cover crops that competed with other plants for water. This factor could have induced the drier soil conditions in the Mow-treated plots in years 2 and 4 (Table 1). The Mow treatment was the only one having a higher water infiltration rate in September than in June of year 6.

Decreased soil pH has been reported in herbicide strips or vegetation removal areas due to the increased leaching of soil cations (2, 12, 14, 32). This was observed during the summer, in the topsoil fraction in our study in both the partially cultivated Mow plots and through vegetation exclusion as a consequence of the dense fabric cover in the BFC

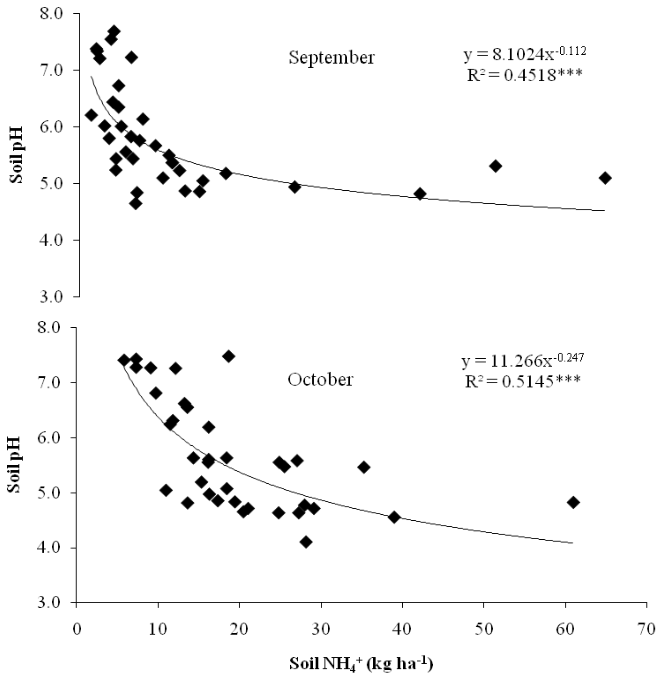

Fig. 3. Relationship between soil [NH_4^+] and soil pH at the depth of 0-15 cm of an organic apple orchard in September and October of year 6 (2005).

plots (Table 2). Greater soil pH at the depth of 0-15 cm in SP plots could have been caused by the high calcium carbonate content in the paper (23), which could have increased soil cation exchange capacity. The organic wood chips provided decomposing sources for OM accumulation in the soil in the sixth season (Figs. 1A and 1B), as reported by Godin et al. (9), while the BFC treatment contributed little to soil OM content.

WC and SP plots showed greater soil [NO_3^-] in June and July in the sixth year of the study, but plots with no or little organic matter input (Mow and BFC) had lower soil [NO_3^-] (Fig. 2A). Mow- and BFC-treated plots had increased soil [NH_4^+] in August and September (Fig. 2B), and a higher [NH_4^+] late in a season could increase soil acidity (decrease soil pH) by undergoing nitrification of the ammonia (32). Soil [NH_4^+] was negatively correlated with soil pH, and soil pH began to increase when [NH_4^+] decreased below 40 kg·ha^{-1} (Fig. 3). Mow and BFC plots, which had lower soil pH, maintained higher soil [Mn] (Fig. 2C), likely inducing higher foliar [Mn]. Low soil pH has been reported in Arkansas and is associated with foliar [Mn] toxicity (18, 28).

Seasonal soil [P] was not considered to be deficient in any GMS treatments (Fig.4A) given current soil phosphorus recommendations for commercial orchards (33). Soil [K] was considerably higher in all the treatment plots than the recommend soil [K] (200 kg·ha^{-1}) for orchards (33). Mg uptake from soil has been shown to be suppressed by heavy K input (7). In our study, insufficient foliar [Mg] (less than 0.3%) was observed in each year (data not presented) possibly because seasonal soil [Mg] in all GMS mulches was less than 200 kg·ha^{-1} (Fig. 4A), the minimum recommended requirement in Northeastern orchards (33). However, WC-treated plots had greater soil [Mg] than other treatments. Although Mow- and BFC-treated plots seemed to have low seasonal soil [Ca] (Fig. 4A) compared with typical values for Northeastern orchards (33), the foliar [Ca] (1.3-1.9%) in August was sufficient in both treatments in each year of the study (data not presented). Increased soil [Ca] in SP-treated plots was most likely because recycled paper contains calcium carbonate to reduce acidity (23). SP plots reduced higher foliar [Mn] in year 6 (Table 4), which has also been reported in an organic apple orchard (22).

Soil [Fe] decreased from April to September (Fig. 4B), and SP-treated plots had overall lower soil [Fe]. The seasonal soil [Zn] ranged from 5 to 35 kg·ha^{-1} in all GMS mulches (Fig.

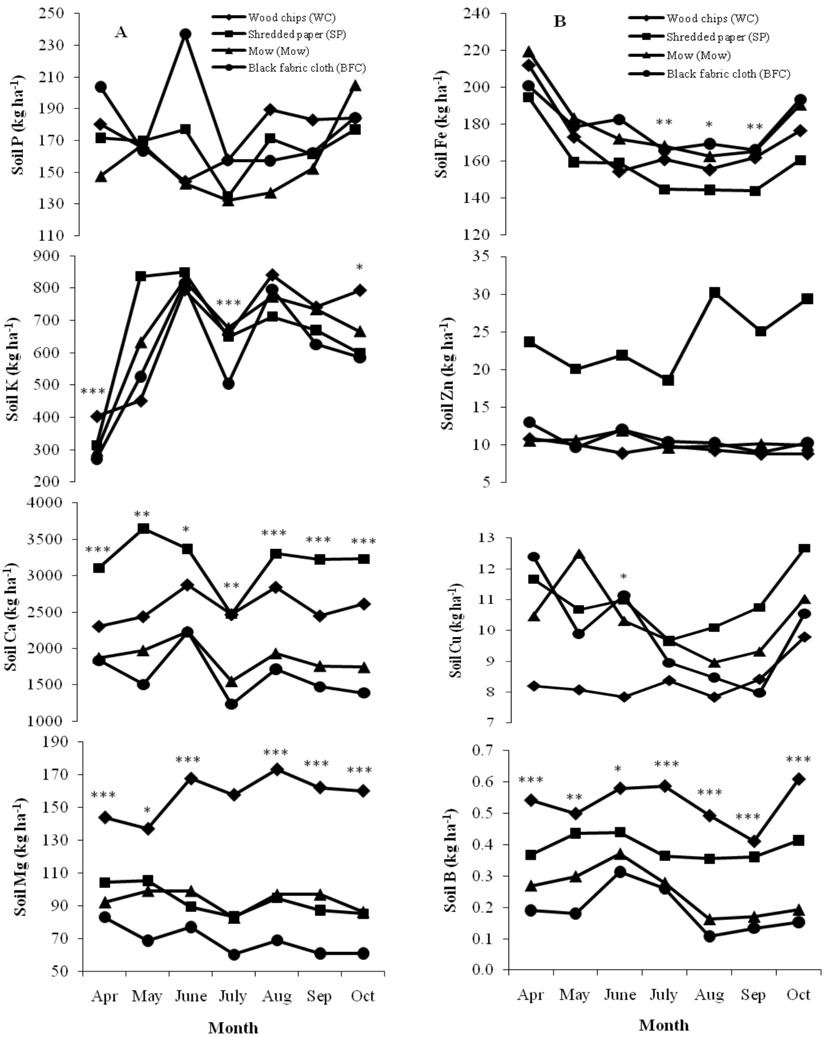

Fig. 4. Seasonal soil macronutrients (A) and micronutrients (B) at the depth of 0-30 cm in an organic apple orchard as affected by ground cover management systems (GMS) from April to October of year 6 (2005).

*, **, ***Significantly different means among ground cover management systems for a particular month at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4. Foliar micronutrient concentrations of cultivar/M.9 apple trees in an organic orchard as affected by ground cover management systems (GMS) and cultivar in August in years 3 (2002), 5 (2004), and 6 (2005).

Treatment	Leaf micronutrient concentration ($mg \cdot kg^{-1}$, dw)										
	Fe			Mn		Cu			B		
	Yr 3	Yr 5	Yr 6	Yr 3	Yr 6	Yr 3	Yr 5	Yr 6	Yr 3	Yr 5	Yr 6
GMS											
Wood chips (WC)	67	167	124	81	122 bc[z]	10.6	11.1	7.7	25.7 a	22.4	16.1
Shredded paper (SP)	56	139	97	71	90 c	11.7	10.5	7.5	24.0 ab	22.7	14.3
Mow (Mow)	67	153	116	94	199 a	11.6	11.6	8.8	24.2 a	22.1	15.6
Black fabric cloth (BFC)	64	152	114	76	182 ab	10.9	9.5	7.6	22.3 b	26.1	14.4
	ns	ns	ns	ns		ns	ns	ns		ns	ns
Cultivar											
Braeburn	67	139	107 b	95	177	12.4 a	11.0	7.5	27.4 a	23.8	17.0 a
Gala	64	157	145 a	81	140	11.0 b	11.0	8.8	22.9 b	20.7	15.3 b
Jonagold	59	160	90 b	70	131	10.4 b	10.6	7.6	21.7 b	24.3	13.1 c
	ns	ns		ns	ns		ns	ns		ns	
P value											
GMS	0.876	0.788	0.552	0.509	<0.05	0.344	0.884	0.281	<0.05	0.110	0.148
Cultivar	0.170	0.522	<0.01	0.077	0.709	<0.05	0.824	0.876	<0.001	0.271	<0.01
GMS × Cultivar	0.378	0.203	0.765	0.561	0.590	0.940	0.225	0.792	0.156	0.220	0.713

[z] Means followed by the same letter within a column are not significantly different according to LSD ($\alpha < 0.05$, n = 6). ns = not significantly different.

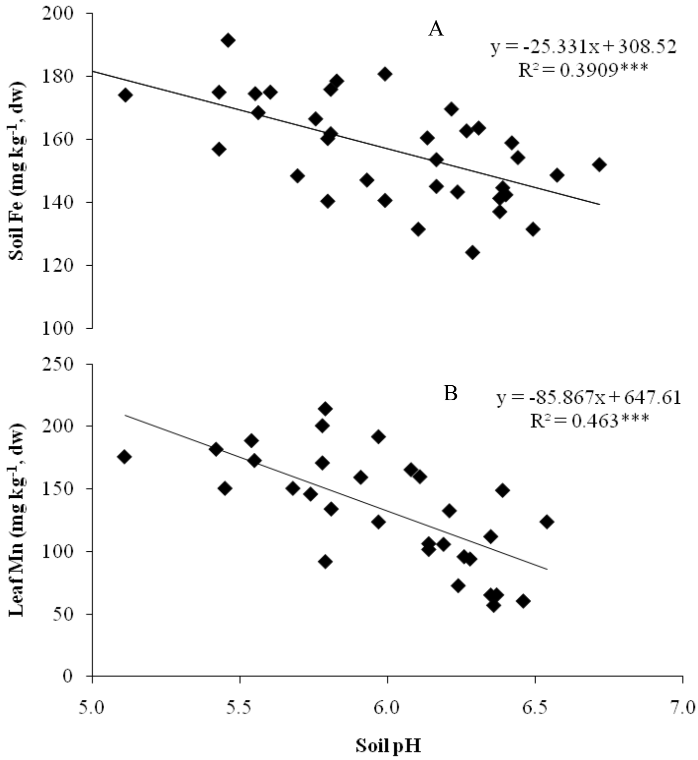

Fig. 5. Relationship between soil pH at the depth of 0-15 cm and soil [Fe] (A) or foliar [Mn] (B) of an organic apple orchard in August of year 6 (2005).

4B) and soil [Cu] varied from April to October (Fig. 4B). The low soil [B] (less than 0.6 kg·ha^{-1}) during each season may have caused insufficient foliar [B] in year 6 (Table 4) based on the recommended [B] levels (33).

'Jonagold' had lower foliar [N] than 'Gala' and 'Braeburn' in year 3 and lower [P] in year 6 (Table 3). Similarly, it had relatively low seasonal [N] compared with other cultivars in an organic orchard in Eastern Europe (17). Trees in all GMS treatments had insufficient foliar [P] in year 6 (Table 3), with a concentration less than the recommended 0.11% (33). Deficient foliar [P] in August was also observed in previous studies where it was reported that low soil pH might have reduced foliar [P] in an Arkansas orchard (18, 28). The threshold level of foliar [P] should be corrected for tree performance and fruit production in the long term. Insufficient foliar [K] was observed on the GMS-treated trees during some years (Table 3) according to the optimal [K] range of 1.3 to 1.8% (33). Relatively large and mature trees with well developed root systems that were used in this study may have resulted in insignificant foliar nutrient differences among the GMS mulches as reported in previous studies (7, 22). Other nonnutritional factors, such as vegetation density and soil moisture, may have also contributed to tree performance.

Mow- and BFC-treated trees had excessive foliar [Mn] in year 6 (Table 4), with concentrations of more than 150 mg·ha^{-1} (33). Excessive foliar [Mn] can induce internal bark necrosis (7, 33). Trees can take up a considerable amount of soluble [Mn] in low soil pH conditions (7, 28), which would likely have influenced foliar [Mn] in this study (Fig. 5B).

The Mow- and BFC- treated plots at the depth of 0-15 cm averaged a pH of 5.6 at the end of July in year 6 (Table 2), which would have induced more available soil [Mn] within the tree root zones (Fig. 2C).

Both foliar [Zn] (data not presented) and [B] were below adequacy ranges during all three years of the study (Table 4), with both concentrations being less than 35 mg·kg^{-1} (33). The apple trees used should have had sufficient water from precipitation and supplemental irrigation to allow for diffusion and uptake of Zn by roots because Zn is mostly influenced by soil moisture (21). Foliar [Zn] deficiency has been associated with formation of foliar rosetting at the shoot tip, as well as reduced flower development, fruit set, and fruit quality (7, 36). These factors contributed to lower yields and smaller trees at an organic apple orchard in the Western USA (26). Foliar [B] in year 3 was highest in the WC- and Mow-treated trees and the lowest in the BFC-treated trees (Table 4).

Foliar [N] linearly decreased from April to September in year 6 ($R^2 = 0.93$) (Fig. 7A) as has been previously observed (1, 5, 7, 16, 17, 18, 24, 29, 37), with little changes found from May to June. Although WC- and SP-treated trees had greater [NO_3^-] at the depth of 0-30 cm in June and July (Fig. 2A), foliar [N] was not affected by GMS during the season. Neilson et al. (20) found that foliar [N] is more affected by vegetation (weed) management than by the N application rates, and earlier vegetation inhibition around trees is an essential strategy for supplying more nutrients. In our study, the BFC treatment completely suppressed undertree vegetation density (0.3%) in year 6 (Fig. 8) and would likely have minimized competition for water and nutrients between the trees and other vegetation. Although lower soil [NO_3^-] was found with the BFC plots in June and July (Fig. 2A), higher foliar [N] was maintained on the BFC plots in May and June (Fig. 7A). Vegetation density should be considered along with the N status of trees grown using mulch treatments.

Seasonal foliar [P] rapidly decreased from April to September in year 6 ($R^2 = 0.82$) (Fig. 7A) as has been previously reported in other studies (1, 5, 7, 16, 17, 18, 24, 29, 37). Leaves showed P deficiency (< 0.13%) in August of year 6 (Table 3), which was probably induced by a low supply of P from early in the season (April) when the foliar nutrient level averaged about 0.28%. In a contrast, a study in Eastern Europe (17) showed that although foliar [P] rapidly decreases from 0.41% to 0.25% in April and May, a deficient level does not occur in August probably due to a high level of

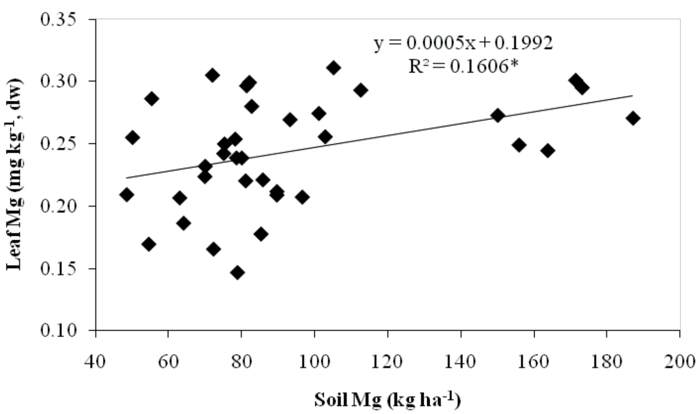

Fig. 6. Relationship between soil [Mg] at the depth of 0-30 cm in July and foliar [Mg] (B) in August of year 6 (2005).

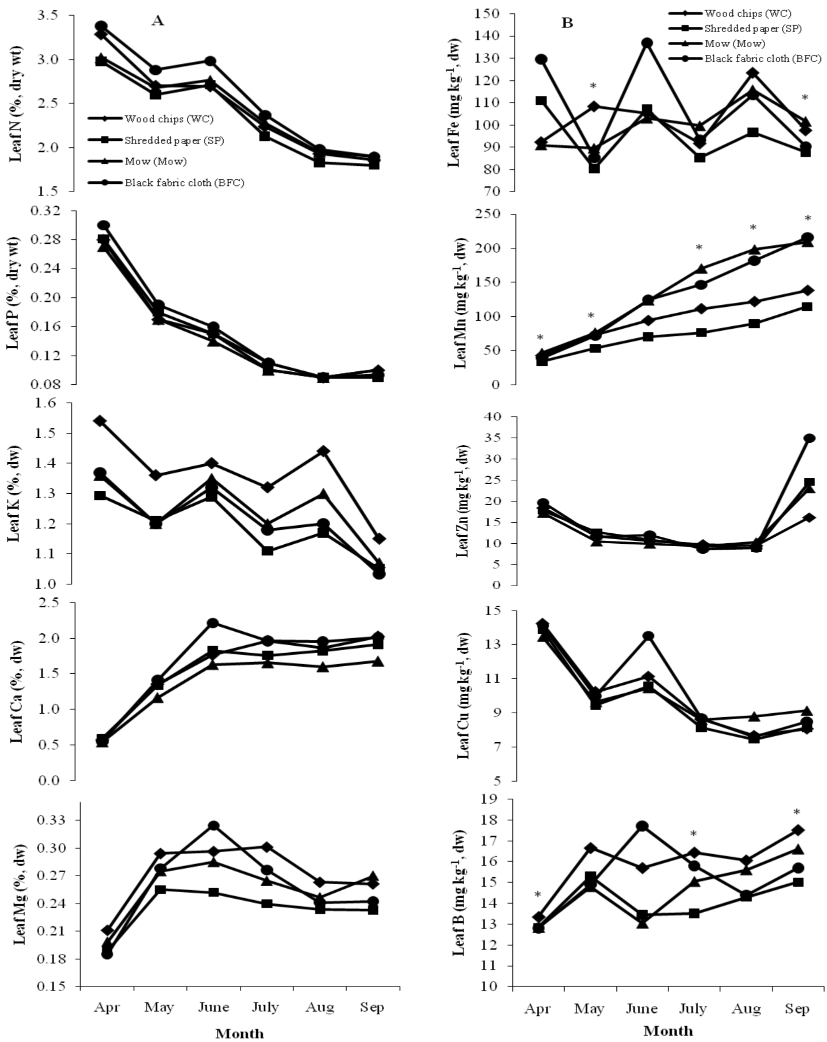

Fig. 7. Seasonal foliar macronutrients (A) and micronutrients (B) of cultivar/M.9 apple trees in an organic apple orchard as affected by ground cover management systems (GMS) from April to September of year 6 (2005).
*Significantly different means among ground cover management systems for a particular month at $P < 0.05$.

foliar [P] in April. The limited root production and low soil pH in our study may have made it difficult for trees to absorb soil [P] when the nutrient was sufficient in previous years (3, 28, 33).

Overall, the [K] decreased ($R^2 = 0.60$) during the season (Fig. 7A) and showed similar patterns to those reported in conventional (1, 5, 16, 18, 24) and in other organic apple orchards (17). Foliar [K] in each treatment slightly increased in June and August as Nagy and Holb (17) reported for an organic apple orchard. [N], [P], and [K] move into new leaves from older leaves within shoots because they are

Table 5. Foliar [N] and [Mn] of cultivar/M.9 apple trees in an organic orchard as affected by ground cover management systems (GMS) and cultivar in August in year 5 (2004).

Treatment	N (%, dw)	Mn ($mg \cdot kg^{-1}$, dw)
GMS		
Wood chips (WC)	2.00 a[z]	71
Shredded paper (SP)	1.88 ab	71
Mow (Mow)	1.79 b	76
Black fabric cloth (BFC)	1.93 ab	123
		ns
Cultivar		
Braeburn	1.80 b	76
Gala	1.97 a	72
Jonagold	1.87 ab	95
		ns
GMS × Cultivar		
WC+Braeburn	1.91 ab	74 b
WC+Gala	2.23 a	79 b
WC+Jonagold	1.75 b	57 b
SP+Braeburn	1.81 ab	65 b
SP+Gala	1.99 ab	73 b
SP+Jonagold	1.89 ab	76 b
Mow+Braeburn	1.74 b	84 b
Mow+Gala	1.83 ab	70 b
Mow+Jonagold	1.82 ab	73 b
BFC+Braeburn	1.86 ab	81 b
BFC+Gala	1.97 ab	170 a
BFC+Jonagold	1.93 ab	65 b
P value		
GMS	<0.05	0.103
Cultivar	<0.01	0.302
GMS × Cultivar	<0.05	<0.05

[z] Means followed by the same letter within a column are not significantly different according to LSD ($\alpha < 0.05$, n = 6). ns = not significantly different.

mobile within the tree (7, 29, 37).

Overall, foliar [Ca] and [Mg] tended to increase curvilinearly in each season (Fig. 7A), which was similar to trends reported for both conventional orchards (1, 5, 16, 18, 24) and organic orchards (17). Insufficient foliar [Mg] in August of year 6 may have been caused by low remobilization of [Mg] from the tree trunk due to the fact that less foliar [Mg] was found in April than the amount reported by Nagy and Holb (17). Mow- and BFC- treated plots had more than optimum levels (50 to 150 $mg \cdot kg^{-1}$) of foliar [Mn] from July to September (Fig. 7B) based on the recommended nutritional levels observed in conventional orchards (33). It has been shown that soil Mn solubility increases below pH 5.5 in arid apple orchards (7, 28), which might explain the increased foliar [Mn] in this study because the drying condition of the experimental plots during the season in year 6 could have been worsened by the insufficient supplemental irrigation. Increased foliar [Mn] late in a season would cause high toxicity in apple trees. The

Table 6. Yield and fruit quality of cultivar/M.9 apple trees in an organic orchard as affected by ground cover management systems (GMS) and cultivar in years 1 (2000) and 2 (2001).

Treatment	Fruit yield ($kg•tree^{-1}$)		Fruit quality: Soluble solids (%)		Starch rating[z]		Fruit juice pH		Firmness (kg)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Braeburn										
Wood chips (WC)	1.2	·	13.1 b	·	6.1	·	3.5	·	8.6 ab	·
Shredded paper (SP)	2.2	1.6 b[y]	14.1 a	13.8 b	7.4	5.7 a	3.6	3.3 a	7.9 b	8.8 a
Mow (Mow)	1.6	·	13.5 ab	·	6.6	·	3.8	·	9.8 a	·
Black fabric cloth (BFC)	2.6	2.8 a	13.8 a	15.6 a	6.3	4.4 b	3.8	2.9 b	10.4 a	7.1 b
	ns				ns		ns			
Gala										
Wood chips (WC)	7.6	10.5 a	15.1 a	11.5 c	5.3	5.1 a	4.2	3.2 a	7.1	8.2 b
Shredded paper (SP)	6.6	9.8 b	16.4 a	10.8 d	5.2	5.1 a	4.1	2.9 d	7.3	8.7 a
Mow (Mow)	9.9	8.3 c	15.4 a	13.5 a	5.0	4.5 c	4.3	3.0 c	7.2	7.9 c
Black fabric cloth (BFC)	8.4	6.3 d	14.8 b	12.2 b	4.7	4.9 b	4.2	3.2 b	7.4	7.5 d
	ns				ns		ns		ns	
Jonagold										
Wood chips (WC)	8.2	6.7 a	14.1	9.6 c	3.5	3.6 c	3.2	3.4 a	8.4	9.2 a
Shredded paper (SP)	5.9	5.7 b	14.6	10.4 b	4.0	5.7 a	3.3	3.4 a	8.2	8.3 c
Mow (Mow)	5.5	4.1 c	14.4	11.0 b	3.1	4.4 b	3.1	3.4 a	8.7	7.8 d
Black fabric cloth (BFC)	7.7	3.1 d	14.8	14.4 a	3.4	3.7 c	3.0	3.2 b	8.8	8.6 b
	ns		ns		ns		ns		ns	

[z] Starch rating on a 0-12 scale; 0 = complete cortical starch; 12 = no cortical starch.
[y] Means followed by the same letter within a column are not significantly different according to LSD ($\alpha < 0.05$, n = 6).
ns = not significantly different.

Table 7. Trunk cross sectional area (TCSA), yield, and yield efficiency of cultivar/M.9 apple trees in an organic orchard as affected by ground cover management systems (GMS) and cultivar in years 3 (2002) and 6 (2005). Growth (%) is calculated as [(TCSAYear6-TCSAYear3)/TCSA Year3] × 100. Yield efficiency is calculated as average yield divided by TCSA.

Treatment	TCSA (cm^2)			Fruit yield ($kg \cdot tree^{-1}$)		Yield efficiency ($kg \cdot cm^{-2}$)	
	Year 3	Year 6	Growth (%)	Year 3	Year 6	Year 3	Year 6
GMS							
Wood chips (WC)	70	81	15 a[z]	6.1	10	0.087	0.115
Shredded paper (SP)	80	86	7 b	4.5	9	0.056	0.104
Mow (Mow)	69	74	7 b	5.2	7	0.073	0.099
Black fabric cloth (BFC)	70	76	9 b	5.8	11	0.081	0.138
	ns	ns		ns	ns	ns	ns
Cultivar							
Braeburn	60 b	67 b	11 a	1.5 b	3 b	0.025 b	0.045 c
Gala	68 b	73 b	7 b	7.8 a	14 a	0.116 a	0.187 a
Jonagold	91 a	99 a	9 ab	7.1 a	11 a	0.084 a	0.109 b
P value							
GMS	0.828	0.689	<0.05	0.809	0.667	0.838	0.417
Cultivar	<0.01	<0.01	<0.05	<0.05	<0.01	<0.05	<0.01
GMS × Cultivar	0.828	0.798	0.098	0.679	0.412	0.821	0.638

[z] Means followed by the same letter within a column are not significantly different according to LSD ($\alpha < 0.05$, n = 6). ns = not significantly different.

organic fertilizer and mulch applications in mid-April did not seem to affect the [Zn] and [B] (Fig. 7B). Seasonal foliar [Cu] decreased in all GMS mulches ($R^2 = 0.70$) (Fig. 7B), which was similar to findings in a conventional apple orchard (16) and in an apple orchard in Arkansas (18).

The absence of strong correlations between elemental soil concentration and leaf composition is not unusual. In another study, where municipal waste was applied to an orchard, there were no direct plant-soil relationships for any nutrients except for [K] due to the complicated interactions with soil properties, competition from weeds, and variations in tree growth or fruit load (27).

WC-treated trees had a greater TCSA increase (%) from years 3 to 6 (Table 7). Yield efficiency was smaller than that found in other studies on organic apple orchards (22, 26) due to the lower yields that were achieved. TCSA was different among cultivars in years 3 and 6 with 'Braeburn' having a smaller TCSA and much lower fruit yield than 'Jonagold', and hence the lowest yield efficiency in the two years which are reported. However, the difference amongst cultivars in the TCSA increase (%) from years 3 to 6 was smaller, probably because each cultivar should have finished its rapid size growth in the earlier years of tree establishment. Vegetative growth, as indicated by incremental TCSA, was not affected by the GMS mulches in the mature trees (which had all been managed similarly prior to the mulch applications) during the scope of this study.

Conclusions

The effects of four GMS (WC, SP, Mow, and BFC) were investigated in an organic orchard in Arkansas. Not surprisingly, the GMS associated with organic materials (WC, SP, and Mow) contributed more to the soil OM than BFC. WC and SP had a greater effect on several soil macronutrients, and WC and

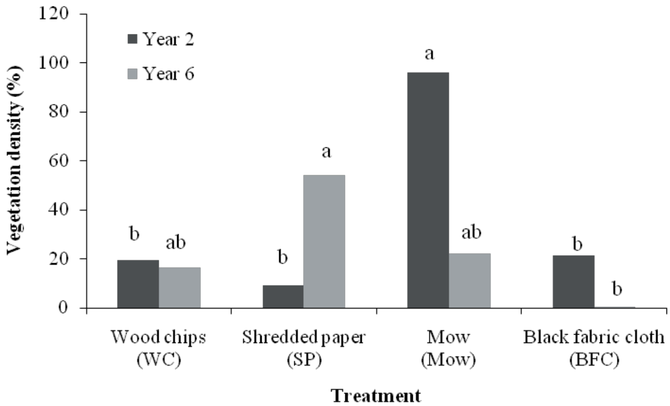

Fig. 8. Undertree vegetation density as affected by ground cover management systems (GMS) in an organic apple orchard in August of years 2 (2001) and 6 (2005).
Different letters on top of the columns indicate significant difference by LSD, 5% level amongst GMS treatments within years.

BFC had better control of the weed population than Mow in the orchard. However, the differences among the GMS treatments were not apparent or sufficient to be reflected on the foliar nutrient status or on the performance of the mature trees used in this study. Seasonal foliar nutrient concentrations of organically managed trees over a 6-year period were similar to those reported for conventionally managed orchards.

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